解答用紙（Answer Sheet）

試 験 科 目 名 Subject	受 験 番 号 Examinee's number
交通工学　Transportation Engineering	M

<注意事項>
全てのページに科目名，受験番号を記入すること。

<Notice>
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Question 1:

(1) Travel-time savings: Reduction in time required for trips; e.g., an expressway that shortens commuting time by 15 minutes.
Vehicle operating-cost reductions: Lower costs for fuel, maintenance, etc., due to improved traffic flow; e.g., smoother traffic reducing fuel consumption.
Traffic-accident cost reductions: Avoided costs from fewer or less severe crashes; e.g., installing median barriers to reduce head-on collisions.

(2) The widely adopted Small (1982) specification expresses the generalized cost (GC) of a trip as follows:

$$GC = \beta_T T + \beta_E SDE + \beta_L SDL$$

Where T is in-vehicle travel time (minutes[1]), $SDE = \max\{PAT - AT, 0\}$ representing schedule-delay-early (minutes arriving before the preferred-arrival time PAT), $SDL = \max\{AT - PAT, 0\}$ representing schedule-delay-late (minutes arriving after PAT). β_T, β_E, and β_L are parameters. GC is measured in generalized-cost units (time or money): lower values indicate higher traveler's welfare.

(3) Empirical studies almost always find $\beta_L > \beta_E$, meaning the penalty per minute of late arrival exceeds that of early arrival: β_L is often 2-3 times larger than β_E. Being late can entail lost wages, missed meetings, or social penalties, whereas early arrival usually results only in waiting time. Consequently, reliability improvements that reduce the probability of lateness yield disproportionately large welfare gains.

(4) Scheduling terms must be modelled explicitly when travelers face critical arrival times, for example:

1. Commuting or business trips tied to work start times or scheduled meetings.
2. Public-transport services with fixed timetables (rail, BRT, long-headway buses).
3. Flights or inter-city services with onward connections, where lateness causes missed transfers.

Ignoring schedule-delay costs in such contexts would systematically understate the benefits of reliability-enhancing investments.

[1] Other units are also acceptable.

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Question 2:

(1) Transport-system resilience is the ability of a road, rail or bus network to withstand a shock, maintain at least a minimal level of service, and then return—or adapt—to an acceptable level of performance within a reasonable time.

(2)

1) Pre-event phase: The network operates under normal conditions, delivering full or near-full capacity.
2) Disruption phase: Immediately after the shock, many links are blocked or damaged, so capacity falls sharply and suddenly.
3) Adaptation phase: Temporary measures such as detours, shuttle buses and contraflow lanes prevent further decline and begin to restore some of the lost capacity.
4) Recovery phase: Permanent repairs and upgrades gradually bring the network back to its original or an improved level of performance.

(3)

Event: July 2018 Heavy Rain Disaster

Pre-event phase: Before the rain peaked, expressways, national highways and railways in the area were operating almost normally.

Disruption (Emergency) phase: During the night of 6–7 July in 2018, the heavy rain triggered hundreds of landslides and wash-outs. By 5:00 on 7 July the authorities had shut 13 expressway routes, about 900 km, roughly 70 % of the entire network in the region. At the same moment, National Routes 2, 31, 185 and 375 and the JR Kure, Sanyo Main and Geibi Lines were all cut, leaving the Hiroshima–Kure corridor effectively isolated. The transport system therefore suffered a very deep and sudden loss of capacity.

Adaptation phase: Despite the shock, road managers quickly exploited two parallel motorways, the Chugoku and Sanin Expressways, to carry east-west traffic and keep a basic lifeline open. They also introduced soft measures such as contraflow lanes, half-price tolls on detour routes, and emergency shuttle buses kept relief convoys and commuters moving. These steps raised effective capacity within a few days, even before major repairs began.

Recovery phase: Structural repairs progressed fast. The key Sanyo Expressway was back in full service on 14 July, barely a week after the peak closures, and all 54 disaster closures on directly managed national highways were cleared by 21 July. Although some local lane restrictions lingered into September, most long-distance traffic flows had already returned to near-normal by late July.

Resilience interpretation: Plotted as a performance-time curve, the episode forms a sharp "V": a very deep initial plunge followed by a rapid rebound. Because resilience is measured by the area under that loss curve, the swift recovery kept the cumulative service loss far smaller than the headline damage suggests. The case shows that, in road networks, redundant routes and agile traffic-management tactics can offset severe initial damage and greatly steepen the recovery slope—thereby delivering high overall resilience.

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Question 3:

(1) A fundamental diagram of traffic flow is a theoretical curve that links the three macroscopic variables of a road stream—flow q (vehicles per hour), density k (vehicles per kilometer) and average speed v (kilometers per hour)—through the identity $q = k \times v$. In practice the diagram is plotted either as a speed-density (v-k) line, which falls linearly from the free-flow speed to zero at the jam density, or as a flow-density (q-k) curve, typically drawn in a triangular shape with an upward "free-flow" branch, a downward "congested" branch and a peak that marks the roadway's capacity (the highest flow it can carry).

Major factors that determine the shape and key parameters are as follows:

Road geometry: The number of lanes, their width, and the presence of steep grades or tight curves directly limit drivers' comfortable speed and safe headway, so they set the free-flow branch and the maximum flow. Example: A straight, four-lane motorway with 3.5 m lanes and gentle grades carries a higher capacity than a two-lane mountain road with 3.0 m lanes and 6 % slopes.

Traffic composition: A larger share of heavy vehicles lengthens following distances and slows acceleration, lowering both free-flow speed and capacity and shifting the congested branch leftward. Example: On a corridor where trucks account for 40 % of vehicles, measured capacity is often 10–20 % lower than on the same road when trucks make up only 5 %.

Control and regulation: Speed limits, ramp metering, signal timing, or lane closures deliberately restrain speed or flow and thus reshape the diagram's peak and critical density. Example: A temporary 60 km/h work-zone limit on a motorway reduces the peak flow from about 2 400 veh/h per direction to roughly 1 600 veh/h.

Environment and weather: Rain, snow, fog, or poor pavement reduce tire grip and visibility; drivers increase headways and cut speed, so the entire diagram drops downward. Example: After heavy snowfall, free-flow speed on an expressway may fall from 100 km/h to 60 km/h and capacity may drop by half even though no lanes are physically blocked.

(2) Queueing at a bottleneck: Suppose that a two-lane motorway normally carries a capacity of 2400 veh/h. At 8:00 a crash blocks one lane, so capacity falls to 1200 veh/h for 30 minutes. Traffic demand entering the section stays at 1800 veh/h during the closure. Using the idea of arrival rate minus service rate (demand minus capacity), (a) state whether a queue will form, and (b) estimate how many vehicles will join that queue by 8:30.

Because the incoming demand of 1800 vehicles per hour exceeds the reduced one-lane capacity of 1200 vehicles per hour, a queue inevitably forms. The difference between demand and capacity is 600 vehicles per hour, so vehicles accumulate upstream at that rate. Over the 30-minute (0.5-hour) closure, the queue therefore grows by about 600 veh/h × 0.5 h = 300 vehicles.

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Question 4:

(1) The multinomial logit (MNL) model assumes that the unobserved utility components ϵ_{ij} are independent and identically distributed across all alternatives and individuals, following a Type I extreme value (Gumbel) distribution. This assumption implies that the error terms are uncorrelated and have identical variance, leading to the closed-form choice probability expression of the logit model. In contrast, the multinomial probit (MNP) model assumes that the vector of error terms $(\epsilon_{i1}, \epsilon_{i2}, \dots, \epsilon_{iJ})$ follows a multivariate normal distribution with mean zero and a general (non-diagonal) covariance matrix. This allows for flexible correlation patterns and heteroskedasticity across alternatives.

(2) Assuming that the traveler chooses the alternative that yields the maximum utility from the finite choice set J, the choice probability can be defined as $P_{ij} = \Pr\left[U_{ij} > \max_{j'(\neq j)} U_{ij'}\right]$. Under the maximization assumption, the logit model can be derived based on U_{ij} being assumed to follow the Gumbel distribution, $Gumbel(\theta_i, V_{ij})$ (Castillo et al., 2008), where the cumulative density function (CDF) and the probability density function (PDF) are: $G_{ij}(U_{ij}) =$

$\exp\left\{-\exp\left(-\frac{\epsilon_{ij}-V_{ij}}{\theta_i}\right)\right\}$, $\theta_i > 0$, and $g_{ij}(U_{ij}) = \frac{1}{\theta_i}\exp\left(-\frac{\epsilon_{ij}-V_{ij}}{\theta_i}\right)\exp\left\{-\exp\left(-\frac{\epsilon_{ij}-V_{ij}}{\theta_i}\right)\right\}, -\infty \le x \le$

∞, respectively. The mean and variance are $\mathrm{E}[U_{ij}] = V_{ij} + \gamma\theta_i$ and $\mathrm{Var}[U_{ij}] = \pi^2\theta_i^2/6$, respectively, where γ is the Euler's constant. Under the independent distribution assumption across alternatives, the choice probability is $P_{ij} = \Pr\left[\max_{j'(\neq j)} U_{ij'}\right] =$

$$\int_{x\in\Omega_g} G_{i1}(x)\cdots G_{ij-1}(x) g_{ij}(x) G_{ij+1}(x)\cdots G_{iJ}\,dx = \int_{x\in\Omega_g}\left\{\frac{1}{\theta_i}\exp\left(-\frac{x-V_{ij}}{\theta_i}\right)\prod_{j=1}^{J}\exp\left\{-\exp\left(-\frac{x-V_{ij}}{\theta_i}\right)\right\}\right\}dx =$$

$$\frac{\exp\left(\frac{V_{ij}}{\theta_i}\right)}{\exp\left(\frac{V_{0i}}{\theta_i}\right)}\int_{x\in\Omega_g}\left\{\frac{1}{\theta_i}\exp\left(-\frac{x-V_{0i}}{\theta_i}\right)\exp\left\{-\exp\left(-\frac{x-V_{0i}}{\theta_i}\right)\right\}\right\}dx = \frac{\exp\left(\frac{V_{ij}}{\theta_i}\right)}{\exp\left(\frac{V_{0i}}{\theta_i}\right)} = \frac{\exp\left(\frac{V_{ij}}{\theta_i}\right)}{\sum_{j'\in J}\exp\left(\frac{V_{ij'}}{\theta_i}\right)}.$$

where Ω_g is the domain of the Gumbel distribution, $J = \{car, bus, train\}$, and $V_{0i} = -\theta_i \ln\sum_{j\in J}\exp(-V_{ij}/\theta_i)$, which is termed logsum. The equation (3) represents the probability P_{ij} that the traveler chooses alternative j.

Note: Full integration of the Gumbel density is not required for full marks. It is sufficient to cite the extreme-value property and show the key logical steps that lead to the multinomial-logit expression.

(3) The multinomial-logit probability satisfies the independence-of-irrelevant-alternatives (IIA) property because the ratio of the probabilities of any two alternatives, say j and k, depends only on the systematic utilities of those two alternatives and on no other option in the choice set:

$$\frac{P_{ij}}{P_{ik}} = \frac{\exp\left(\frac{V_{ij}}{\theta_i}\right)}{\exp\left(\frac{V_{ik}}{\theta_i}\right)} = \exp\left(\frac{(V_{ij}-V_{ik})}{\theta_i}\right)$$

Since this odds ratio is unaffected by adding, removing, or changing the attributes of any third alternative, the choice between j and k is "independent" of all irrelevant alternatives; that invariance is the defining feature of IIA.

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問１

（1）

地球規模の種多様性の空間的パターンには、緯度勾配が見られる。種多様性は低緯度の熱帯地域で最も高く、中緯度の温帯、高緯度の亜寒帯・ツンドラ（極地）に向かうにつれ、種数が減少する。

メカニズムについては、下記の仮説などから２つ説明することを想定する。

- 歴史的仮説
- エネルギー・生産性仮説
- 環境の不均一性仮説　など

（2）

植物群集における冗長性とは、異なる植物種が生態系内で同様の生態的機能（例：成長速度、乾燥耐性、耐陰性、炭素固定、窒素固定、土壌安定化、水分保持能力など）を担っている状態をいう。このような群集では、ある種の個体数が減少したり、または失われたりしても、同じ機能を持つ他種がその役割を補完できるため、生態系全体の機能やプロセスが大きく損なわれることがない。

下記のメカニズムをもとに答えることを想定する。

- Insurance hypothesis に基づくメカニズム
- Response diversity に基づくメカニズム

（3）

被食者動物が捕食者動物の存在を認識・危惧することによって、その行動や空間利用パターンが変化する現象、およびその結果として形成される空間的なパターンを指す概念である。単なる捕食者との直接的な相互作用だけでなく、捕食リスクの認識自体が被食者の行動に継続して影響を与える。被食者動物が生息地を移動する際に、捕食者動物による捕食リスクが高い場所（危険な場所；例えば、身を隠すカバーがない、または、捕食者が待ち伏せしやすい茂みがある、捕食者の位置が特定しにくい見通しの悪い場所、捕食を回避しにくい地形、など）を避け、リスクの低い場所（安全と考えられる場所；カバーがある、逃げやすい地形、など）を優先的に利用する。このリスクの空間的な違いが、

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被食者にとっての landscapes of fear を創出する。

また、動物が周囲の環境を見渡し、捕食者などの潜在的な脅威を早期に発見しようとする行動を警戒行動（vigilance）という。例えば草食哺乳類であれば、頭を上げて周囲を見渡したりするなど、観察可能な行動として現れる。警戒時間配分が増えると、採餌時間配分が減少するため警戒行動は被食者にとってコストとなり得る。そのため、landscapes of fear は被食者の適応度にも繋がる概念である。

問 2

出題の意図

下記のポイントを総合的に評価するために、本問題を出題した。

・応用生態学（生態学的再野生化 ecological rewilding など）や基礎生態学（栄養カスケード trophic cascade など）の幅広い知識を有し、それらに基づいて自身の意見を述べられているか

・　基本的なアカデミックライティング（エッセイのパラグラフ構成、パラグラフ内の構造、文章表現力など）の知識およびスキルを有しているか

・　論理的思考力の程度（全体を通して、首尾一貫した論理的記述がされているか）

問 3

出題の意図

下記のポイントを総合的に評価するために、本問題を出題した。

・　生態学研究に対するモチベーション、知識

・　自立的な学習能力（自身の興味を掘り下げ、意欲的・自主的に学習を進める能力があるか）

・　自身の興味に応じた生態学の研究分野、および理論や概念の理解力