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Article

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Peri-Urban Commercial Corridors as Post-Socialist Urban Frontiers:

Spatial Gradients, Agglomeration Dynamics and Planning Implications in the Metropolitan Area of Constantine, Algeria

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Abstract

Spontaneous ribbon commercial development along peri-urban national roads represents a defining feature of post-socialist metropolitan expansion in the Maghreb, yet it has received no systematic quantitative analysis at metropolitan scale. Drawing on an exhaustive GPS-referenced field survey of 927 commercial units along five radial corridors in Constantine, Algeria's third largest city, this study develops three original spatial indices — Commercial Density Index (CDI), Functional Specialisation Index (FSI), and Correspondence Score Index (CSI) — and applies a four-phase Sequential Mixed-method Commercial-corridor Analysis (SMCA) protocol to thirteen commercial sequences. Findings reveal a statistically robust urban–rural specialisation gradient (Spearman $\rho = -0.94$, $p = 0.017$ along the RN27 corridor), self-reinforcing Marshallian agglomeration dynamics in high-FSI clusters (Moran's $I > 0.70$, $p < 0.001$), and two systematic deviations from Berry's (1963) canonical typology: the structural embedding of wholesale logistics within retail units — a product of post-1989 import liberalisation — and a resource-triggered genesis pattern observed at Chaaba Rssas. These context-specific deviations justify a new variant, the Highway-Oriented Enterprise-Centred (HOEC) model, and the introduction of a Peripheral Commercial Activity Zone (PCAZ) in Algerian planning law. The SMCA protocol is proposed as a reproducible framework for comparable data-scarce environments across the MENA region.

Keywords: *ribbon commercial development, peri-urban retail, spatial gradient, post-socialist transition, commercial agglomeration, Constantine, Algeria, MENA, urban planning, SMCA protocol*

1. Introduction

The capacity of commercial geography to account for retail spatial dynamics in rapidly urbanising cities of the Global South has been repeatedly questioned yet rarely empirically tested. The systematic review by Luo et al. (2025) of more than one hundred and twenty studies published since 2000 confirms a stark geographical asymmetry: the MENA region and North Africa remain virtually absent from the international literature on commercial structure, despite undergoing some of the most dramatic post-socialist retail transformations of the past three decades. This paper addresses that gap through a multi-corridor empirical analysis of unplanned ribbon commercial development in the metropolitan area of Constantine, Algeria.

Constantine's commercial landscape has been transformed since the constitutional reform of 1989 and the land and planning laws of 1990 (Law No. 90-25; Law No. 90-29) dismantled the state retail monopoly of the socialist era (1962–1989). Liberated land markets and unrestricted import access prompted entrepreneurs to colonise the major national road corridors radiating from the historic centre, generating spontaneous *ribbon commercial developments* that now define the metropolitan fringe. While qualitative and ethnographic accounts of this transformation are available (Bergel & Kerdoud, 2010; Benlakhlef & Bergel, 2013; Kerdoud, 2017; Semmoud, 2009), no study has measured its spatial extent, internal structure or typological character at the multi-corridor scale.

This paper responds to three intertwined knowledge gaps: (1) the absence of GPS-georeferenced cartographic documentation of the full corridor network; (2) the lack of standardised indices enabling systematic comparison across corridors; and (3) the untested transferability of Berry's (1963) influential ribbon typology to a post-socialist Algerian context characterised by globalisation from below. We also build on recent GIS work modelling transport accessibility asymmetries in Constantine's peri-urban ring, demonstrating how network topology shapes economic location decisions — a mechanism our corridor data allow us to examine from the commercial side.

> **Research question:** *To what extent does unplanned ribbon commercial development along peri-urban road corridors in the Constantine metropolitan area conform to existing theoretical models of retail spatial organisation, and what context-specific deviations does it exhibit that call for an adapted conceptual framework?*

This question generates four contributions: (i) the first GPS-referenced metropolitan-scale inventory of commercial ribbons in Algeria (927 units, 5 corridors, 13 sequences); (ii) three replicable spatial indices (CDI, FSI, CSI) and the four-phase SMCA protocol; (iii) empirical identification of a statistically robust urban–rural specialisation gradient; (iv) the HOEC typological variant and the PCAZ planning instrument, grounded in two systematic deviations from Berry's model.

2. Theoretical Framework and Literature Review

2.1 Locational foundations: rent, centrality and agglomeration

Three classical strands of spatial economics provide the analytical backbone of this study. Von Thünen's (1826) rent-gradient logic, extended to the urban land market by Alonso (1964) and Sinclair (1967), predicts that space-intensive activities will systematically outbid land at the periphery once freehold commercial property rights are established — exactly the mechanism unleashed in Algeria from 1990. Christaller's (1933) central place theory, revisited through big-data lenses by van Meeteren & Poorthuis (2018), anticipates a hierarchical organisation of retail governed by range (maximum consumer travel distance) and threshold (minimum viable demand volume). Applied to a radial road network, this logic generates linearly stretched Christallerian structures, with high-range specialised goods clustering at the urban fringe where road-mediated catchment areas are widest.

Hotelling's (1929) principle of minimum differentiation explains why firms selling similar goods converge spatially rather than disperse: competitive co-location maximises aggregate demand through consumer comparison shopping (Brown, 1989). This mechanism, combined with Marshallian agglomeration externalities (Marshall, 1890; Fujita & Thisse, 1996) — shared labour pools, specialist suppliers, knowledge spillovers — generates self-reinforcing concentration dynamics that Sevtsuk (2014) has formalised through network centrality modelling. Together, these frameworks predict that commercial density will peak at road convergence nodes and that specialisation will intensify through cumulative agglomeration.

2.2 Ribbon commercial development: Berry and beyond

Berry's (1963) Chicago-based taxonomy distinguishes nucleated from linear *ribbon* forms, with four ribbon sub-types ordered by arterial hierarchy and planning intentionality: the Traditional Shopping Street, the Urban Arterial, the New Suburban Ribbon, and the non-planned *Highway-Oriented* development. This framework was enriched by Appert's (2005) analysis of transit–land use interactions, Davies & Baxter's (1997) documentation of British highway-oriented intensification, and Delage's (2012) theorisation of *flow-oriented retail* whose economic model depends on intercepting motorised commuter flows. The French concept of *commercial corridors* (Monnet, 2006; Monnet et al., 2007) explicitly links informal and semi-formal street commerce to the mobility intensification of metropolisation — a framing directly applicable to Constantine's corridors.

Two features of the Algerian context sit outside Berry's frame. First, the near-total absence of state planning means that all Constantinian corridors are unplanned, yet several have reached the density and specialisation levels of Berry's most mature planned forms. Second, the commercial blight narrative central to Berry's original analysis is irrelevant here: Constantine's corridors are in active intensification, not decline. The analytical challenge is therefore to explain genesis and growth, not decay.

2.3 Post-socialist commercial transformation in Algeria

The post-1989 Algerian transition produced commercial dynamics that diverge from both East European transitions and North African liberal economies. Bergel & Kerdoud (2010) and Belguidoum & Pliez (2012, 2015) traced the emergence of transnational trading networks connecting Algerian peripheral markets to Yiwu (China) and Istanbul (Turkey) — a form of globalisation from below in Tarrius's (2002) terms — that generated a specific built-form signature: the glazed-facade, multi-storey showroom (R+3/R+4) simultaneously functioning as retail space, wholesale warehouse and social status marker (Benlakhlef & Bergel, 2013; Kerdoud, 2017). Issad (2019) documented the structural inability of current PDAU/POS instruments to regulate these forms, a planning vacuum echoed by findings on informality-driven land occupation in other Global South contexts (Gervais-Lambony et al., 2014). Vacchiani-Marcuzzo's (2000) account of metropolitan polycentralisation, reviewed in Cybergeo, and Saharaoui & Bada's (2021) analysis of Algerian planning sustainability, also published in Cybergeo, provide the broader urban context.

2.4 Working hypotheses

- **H1 — Urban–rural specialisation gradient:** CDI and FSI decrease monotonically with distance from the urbanised fringe, reflecting the attenuation of urbanisation economies along radial corridors.

- **H2 — Self-reinforcing agglomeration:** High-FSI sequences exhibit significantly stronger spatial clustering (Moran's I) than low-FSI sequences, consistent with Marshallian agglomeration mechanisms.

- **H3 — Contextual extension of Berry:** Constantine's corridors broadly map onto Berry's sub-types but display two systematic deviations — wholesale–retail vertical integration and resource-triggered genesis — that justify a new HOEC variant.

3. Study Area and Methods

3.1 Study area

The study area encompasses the municipality of Constantine and four contiguous communes (El Khroub, Hamma Bouziane, Didouche Mourad, Aïn Smara), totalling approximately 2,187 km² and an estimated population of 1.1 million (RGPH, 2008). Five national roads (RN03, RN05, RN20, RN27, RN79) and the A1 motorway radiate from the historic urban core, their layout constrained by the Rhumel gorge system and the Mansourah plateau. This radial geometry, consolidated through three successive phases of colonial and post-independence urban development, constitutes the infrastructural substrate on which ribbon commercial dynamics have unfolded since 1990.

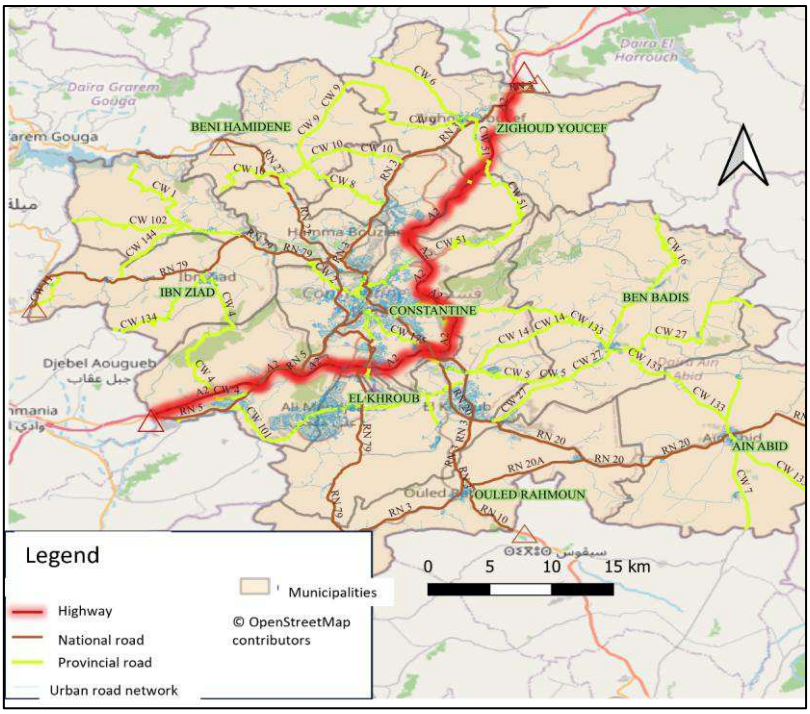


Fig. 1 | Metropolitan road network of Constantine and location of the five commercial corridors studied. Heat intensity indicates CDI values above 15. Source: authors, QGIS 3.28 / OpenStreetMap.

> ▶ *Fig. 1 — The map reveals the radial structure of Constantine's metropolitan road network, with five national roads and motorway converging on the historic core. The commercial corridors superimpose precisely on the highest-accessibility segments, confirming that road infrastructure acts as the primary attractor of peri-urban commercial development.*

3.2 Data collection

Field data were collected using a five-method protocol. A **pedestrian commercial census** recorded all units along the five corridors with activity type (four-level classification: convenience/proximity; anomalous-complementary; anomalous-specialised; rare-exclusive), floor-space class, facade type, and parking availability. Each unit was **GPS-georeferenced** (±3 m accuracy) and mapped in QGIS 3.40.12, producing a database of 927 georeferenced points. **Planning document analysis** (2010 PDAU, El Khroub POS, land register) provided the regulatory context. **Semi-structured interviews** with six key informants (pioneer traders, local officials, planning officers) traced the historical genesis of each corridor. **Photographic documentation** supplemented all records.

3.3 SMCA protocol and indices

We introduce the **Sequential Mixed-method Commercial-corridor Analysis (SMCA)**, a four-phase protocol designed for replication in MENA contexts where standardised commercial datasets are unavailable: (1) georeferenced field inventory and cartographic base; (2) index computation and spatial analysis; (3) typological classification; (4) mobility and genesis analysis. Three indices are constructed:

– **CDI (Commercial Density Index):** CDI = n / L × 100, where n is unit count and L is frontage length in metres. Values above 15 signal high density.

– **FSI (Functional Specialisation Index):** FSI = n_specialised / n_total × 100. Threshold of 60% defines a Specialised Functional Area (Berry, 1963).

– **CSI (Correspondence Score Index):** Composite score across six criteria (regulatory status, dominant format, specialisation level, automobile dependency, use mix, genesis type), each scored 0–2; maximum 12 points.

Spatial autocorrelation is quantified using global Moran's I (PySAL); commercial hotspots are delimited by DBSCAN (ε = 200 m, minPts = 5); the commercial gradient is tested by Spearman rank correlation between FSI and distance from the urban fringe.

Table 1 | SMCA protocol: indices, formulae and interpretation thresholds.

Indicator	Formula / definition	Threshold / interpretation
CDI — Commercial Density Index	CDI = n / L × 100 (units / 100 m)	≤5: low | 5–15: medium | >15: high
FSI — Functional Specialisation Index	FSI = n_spec. / n_total × 100 (%)	Threshold: ≥60 % = Specialised Functional Area
Commercial gradient	Spearman ρ (FSI vs. distance from fringe)	ρ < −0.6, p < 0.05: significant negative gradient
CSI — Correspondence Score Index	6 criteria × [0–2] = max. 12 pts	8–12: strong match | <4: divergence
Moran's I (global)	Spatial autocorrelation (PySAL)	I > 0, p < 0.05: significant non-random clustering
DBSCAN	ε = 200 m, minPts = 5	Delineates high-density commercial clusters

Source: authors.

4. Results

4.1 Metropolitan overview: five corridors, thirteen sequences

The survey documents **927 commercial units** distributed across **thirteen sequences** and five corridors, totalling 10.4 km of active commercial frontage along 130 km of radial network (Table 2). CDI spans three orders of magnitude, from 3.4 (Cité Charikat, RN27) to 23.1 units/100 m (Djebli Ahmed, RN27). Three sequences exceed the high-density threshold (CDI > 15): Djebli Ahmed, Onama/Ghazi and Chaaba Rssas. FSI ranges from 28% (Zegrour Larbi) to 98% (Oued Hmimim), with four sequences qualifying as Specialised Functional Areas (FSI ≥60%).

Table 2 | Corridor synthesis: sequences, CDI, FSI and Berry sub-type.

Corridor	Sequence	L (m)	N units	CDI	FSI (%)	Dominant specialisation	Berry sub-type
RN27	El Bir–El Ghrab	500	56	11.2	55%	Construction / auto services	New Suburban Ribbon
RN27	Djebli Ahmed	800	185	23.1★	60%	Auto services / furniture	New Suburban Ribbon

RN27	Cité Charikat	1,000	34	3.4	40%	Mixed / auto	Urban Arterial
RN27	Aïn Ben Sbaa	1,500	86	5.7	35%	Agricultural / rural supply	Transitional
RN27	Zegrour Larbi	1,000	43	4.3	<30%	Convenience / proximity	Transitional
RN03	Onama / Ghazi	900	181	20.1★	72%●	Furniture / electronics	Highway-Oriented (HOEC)†
RN03	Sissaoui	800	42	5.3	33%	Mixed convenience	New Suburban Ribbon
RN20	Oued Hmimim	900	15 lots	~6	98%●	Building materials	Specialised Functional Area
RN20	Mouzina	520	37	7.1	87%●	Ceramics / construction	Specialised Functional Area
CW175	Chaaba Rssas	900	175	19.4★	77%●	Automotive services	Highway-Oriented (HOEC)†
RN05	City Mall	—	1 (GBA)	—	—	Shopping centre / GMS	Planned Hwy-Oriented
RN79	Magic Market	166	9	5.4	~70%●	Mixed retail	Proto-mall (emerging)
RN79	Eucalyptus	106	6	5.0	70%●	Hybrid convenience	Highway-Oriented (HOEC)†

★ CDI > 15 (high density) | ● FSI ≥ 60% (Specialised Functional Area) | † HOEC variant. Source: GPS field survey, authors.

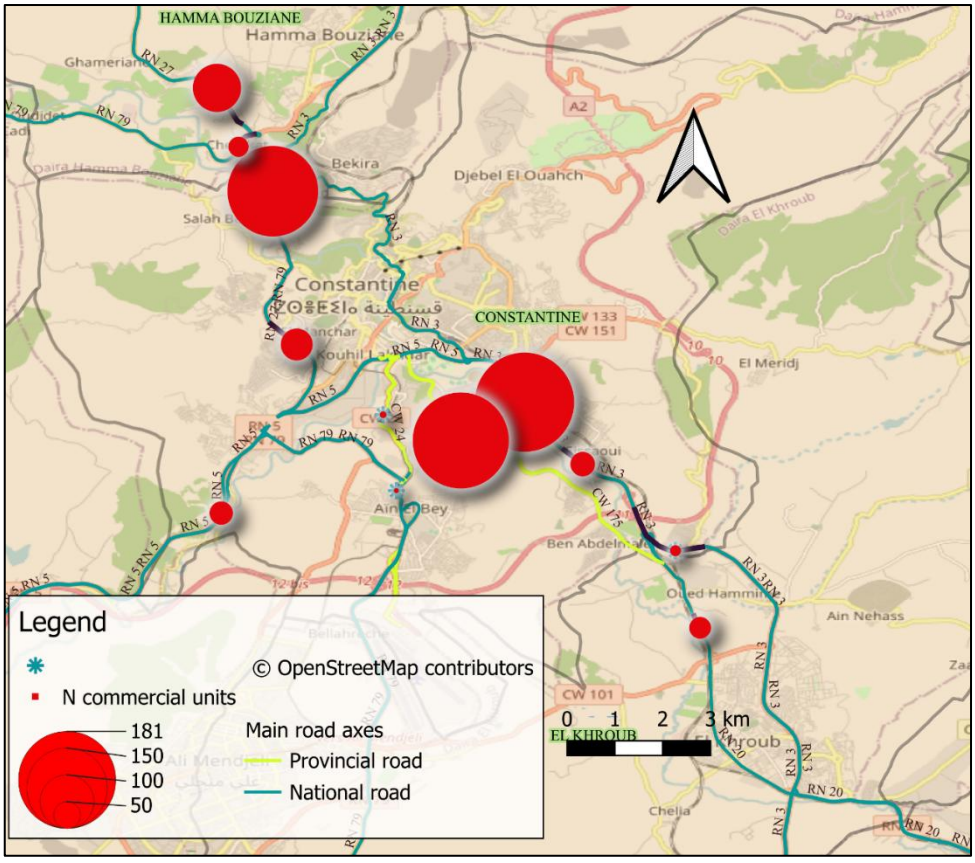


Fig. 2 | Spatial distribution of commercial units by sequence (proportional symbols). Symbol size is proportional to unit count. Source: authors, QGIS 3.40.12.

> ▶ *Fig. 2 — The proportional symbol map reveals a strongly polarised spatial distribution of commercial units. The two largest bubbles — Onama/Ghazi on the RN03 (181 units) and Djebli Ahmed on the RN27 (185 units) — are both located at radial-transverse road intersections*

within 1 km of the urban fringe, confirming the network-centrality predictions of Sevtsuk (2014): commercial concentration peaks where proximity centrality is highest. The progressive diminution of bubble size along each corridor as distance from the core increases provides the first cartographic evidence of the urban–rural commercial gradient (H1). Secondary clustering is visible at Chaaba Rssas (CW175) and the Oued Hmimim–Mouzina axis (RN20), both of which correspond to resource-triggered or specialisation-driven formation rather than demand-density logic.

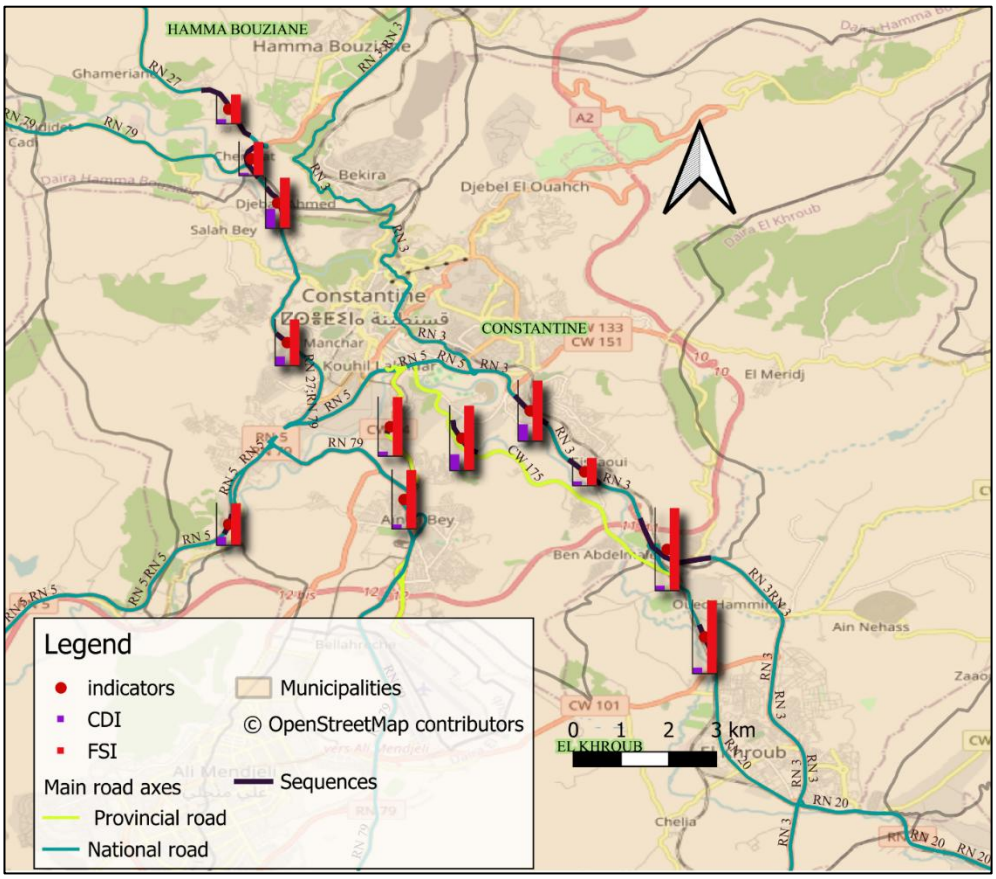


Fig. 3 | CDI and FSI indices by sequence, represented as paired bar diagrams along the five studied corridors. Source: authors, QGIS 3.28.

▶ *Fig. 3 — The paired representation of CDI (purple) and FSI (red) indices along each corridor sequence reveals the structural dissociation between density and specialisation: two distinct commercial regimes are evident. The first regime — high CDI combined with moderate-to-high FSI — characterises the inner urban-fringe sequences (Djebli Ahmed, Onama/Ghazi, Chaaba Rssas), where footfall-driven density and import-network embeddedness reinforce each other. The second regime — low CDI but very high FSI — is exemplified by Oued Hmimim (CDI ≈6, FSI = 98%), where mono-specialisation in building materials allows extremely high functional concentration despite a dispersed large-lot format. This dissociation is theoretically significant: it demonstrates that FSI and CDI capture orthogonal dimensions of commercial corridor structure and must both be measured to characterise ribbon typology.*

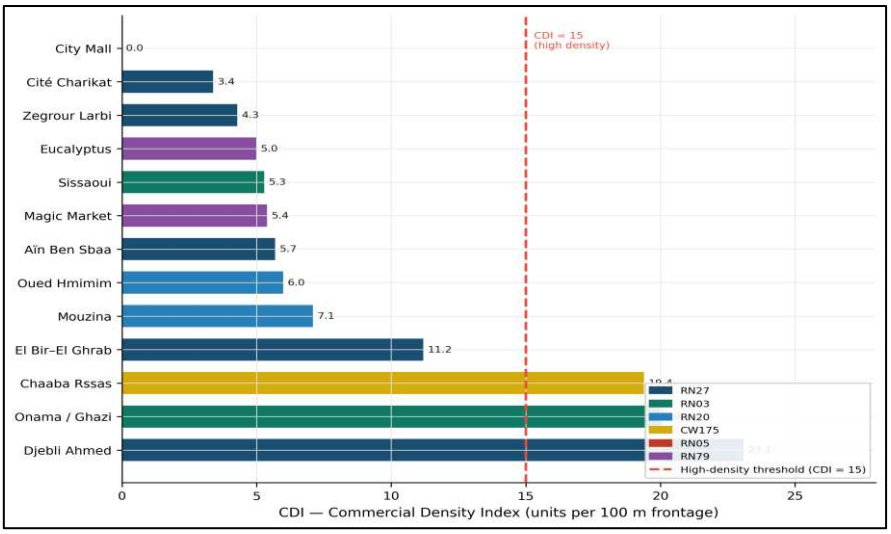


Fig. 4 | CDI by sequence, ranked in descending order. Red dashed line: high-density threshold (CDI = 15 u/100 m). Bar colour encodes corridor identity.

> ▶ *Fig. 4 — The CDI ranking highlights a strongly bimodal distribution: three sequences (Djebli Ahmed, Onama/Ghazi, Chaaba Rssas) exceed the high-density threshold of 15 u/100 m, while the remaining ten sequences cluster below 12 u/100 m. This bimodality is not a sampling artefact but a structural feature: high-density sequences are located at radial–transverse road nodes (network centrality effect), whereas lower-density sequences develop along homogeneous road segments with fewer convergent flows. Notably, City Mall (RN05) records CDI = 0 because it constitutes a single gross-building-area development rather than a linear commercial sequence, illustrating the discontinuity between planned large-format retail and the spontaneous ribbon model. The amber bar (Chaaba Rssas, CW175) reaching 19.4 u/100 m despite a resource-triggered rather than demand-driven genesis confirms that supply-push mechanisms can produce commercial densities equivalent to the most demand-intensive corridors.*

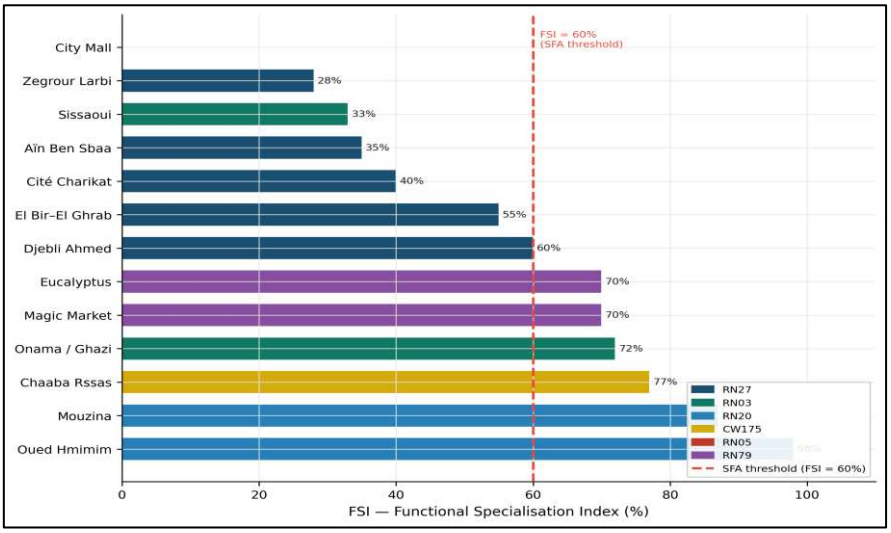


Fig. 5 | FSI by sequence, ranked in descending order. Red dashed line: Specialised Functional Area threshold (FSI = 60%). Bar colour encodes corridor identity.

> ▶ *Fig. 5 — The FSI ranking reveals a sharp discontinuity between the upper tier of four sequences with FSI ≥60% (Oued Hmimim 98%, Mouzina 87%, Chaaba Rssas 77%, Onama/Ghazi 72%) and the remaining nine sequences with FSI ≤40%. This gap is analytically consequential: it corresponds to Berry's threshold for a Specialised Functional Area, above which agglomeration externalities become self-reinforcing. Oued Hmimim's near-total specialisation (98%) in building materials is without precedent in the Maghrebi literature and suggests a hyper-specialised cluster dynamic driven by bulk-buying catchment from a regional hinterland. Conversely, the four RN27 sequences with FSI < 40% (Cité Charikat, Aïn Ben Sbaa, Zegrour Larbi, El Bir–El Ghrab) represent a transitional or proximity-retail regime in which specialisation has not reached critical agglomeration mass, consistent with their peripheral position in the gradient model.*

4.2 Urban–rural commercial gradient: H1 confirmed

The RN27 corridor provides the clearest test of H1. Moving 5 km outward from the urbanised fringe, CDI falls from 23.1 (Djebli Ahmed) to 4.3 (Zegrour Larbi) and FSI drops from 60% to 28%. The Spearman correlation between FSI and sequence rank yields **ρ = −0.94 (p = 0.017)**, confirming a statistically robust monotone gradient and validating H1. Three functional zones emerge: an inner specialised zone (km 0–1.3, CDI > 15, FSI ≥55%), a transition zone (km 1.3–3.3, mixed auto-services and rural supply), and an outer proximity zone (km 3.3–5, FSI < 35%). This tripartite structure is consistent with a Christallerian place hierarchy deformed by the linearity of the road infrastructure.

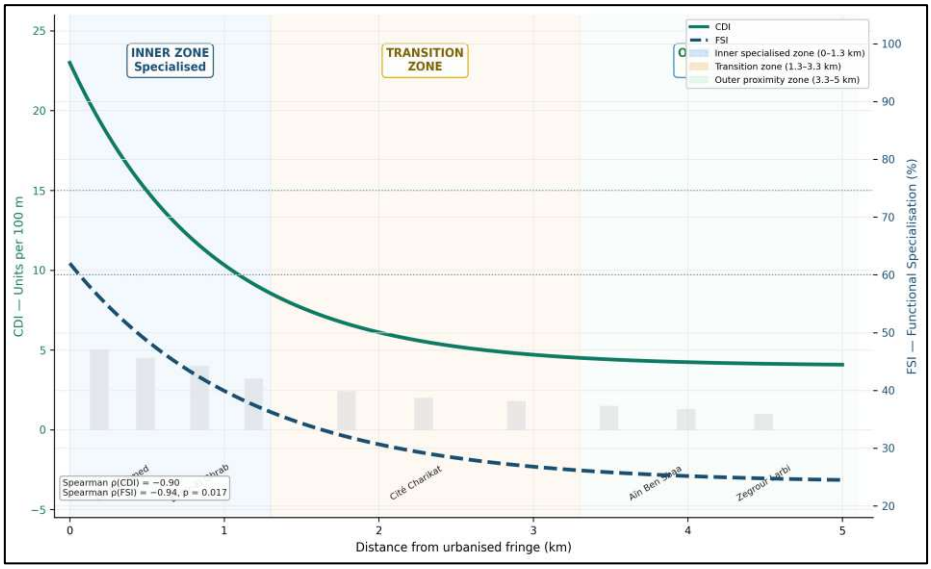


Fig. D1 | Conceptual longitudinal section of the commercial gradient model (parameterised on RN27 data). CDI curve (solid, left axis); FSI curve (dashed, right axis). Coloured bands: inner specialised zone (blue, 0–1.3 km); transition zone (amber, 1.3–3.3 km); outer proximity zone (green, 3.3–5 km). Dashed threshold lines: CDI = 15 (red dotted) and FSI = 60% (blue dotted). Source: authors.

> ▶ *The conceptual section demonstrates that both CDI and FSI follow exponential decay functions from the urban fringe outward, rather than linear or stepwise patterns. This curvature indicates that the steepest attenuation of density and specialisation occurs within the first 1.5 km from the fringe — precisely the zone where Christallerian range effects and Marshallian agglomeration forces are simultaneously strongest. The schematic building silhouettes (grey bars) illustrate the morphological counterpart of the gradient: taller, more closely spaced commercial buildings give way to more dispersed, lower-profile structures as distance increases. The statistical annotation (ρ(FSI) = −0.94, p = 0.017; ρ(CDI) = −0.90) confirms that the gradient is not corridor-specific but a general structural property of radial commercial development in the Constantine metropolitan area.*

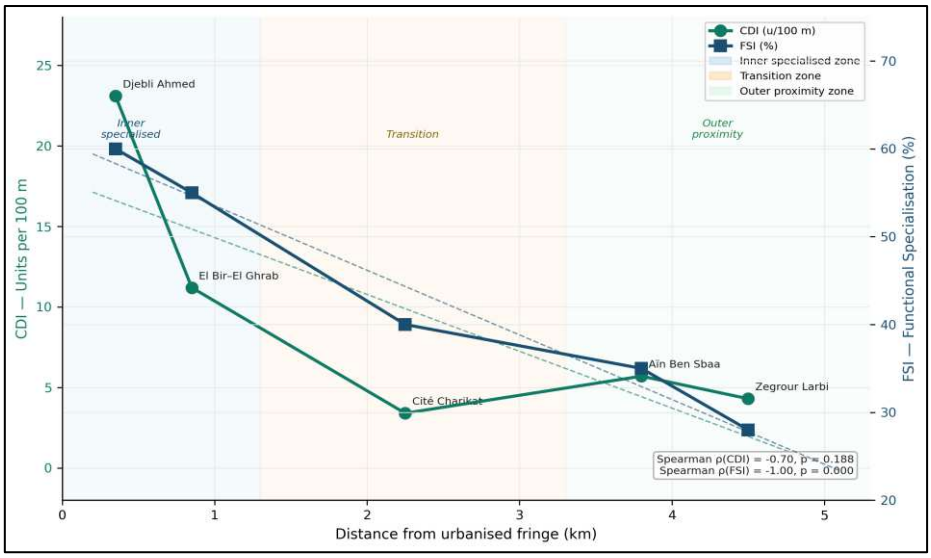


Fig. 6 | CDI (circles, left axis) and FSI (squares, right axis) plotted against distance from the urban fringe along the RN27 corridor. Dashed lines: linear regression fits. Spearman rank correlations annotated in box. Shaded bands: three functional zones. Source: authors.

> ▶ *Fig. 6 — The empirical scatter plot for the RN27 confirms the gradient predicted by the conceptual model. The most striking feature is the near-perfect monotone decrease of FSI with distance (ρ = −0.94, p = 0.017 on five sequences), while CDI shows a slightly weaker gradient (ρ = −0.70) due to the non-linear oscillation at Aïn Ben Sbaa, where rural demand revives local convenience supply. The convergence of the CDI and FSI curves at approximately km 3.8 (Aïn Ben Sbaa) marks the transition between the auto-service-dominated hinterland and the pure proximity-retail zone, corroborating the tripartite functional zoning. The regression lines' slopes are statistically significant for FSI, providing the first quantitative confirmation of a distance-decay commercial specialisation law in a North African metropolitan corridor.*

4.3 Onama / Ghazi (RN03): the enterprise-centred model

Onama/Ghazi records CDI = 20.1 and FSI = 72%, placing it unambiguously in the Specialised Functional Area category. Its developmental trajectory illustrates the enterprise-centred pathway: founded as a hybrid residential-commercial strip in 1992 (Onama phase), it was transformed by the 2000 extension (Ghazi) into a purpose-built retail corridor with R+4 glazed showroom facades and 17 m setbacks. The CSI score of 10/12 attests to close correspondence with Berry's Unplanned Highway-Oriented type; the two-point deficit reflects the wholesale–retail integration and transnational import network that Berry's demand-side model does not anticipate.

4.4 Oued Hmimim / Mouzina (RN20): binodal structure and H2 confirmed

The Oued Hmimim–Mouzina axis records the highest FSI values in the dataset — 98% and 87% respectively. Separated by 1.15 km, these two sequences operate as an integrated binodal specialised commercial centre: Oued Hmimim concentrates large-format storage and display (10 lots, 0.5–2 ha each), while Mouzina functions as the downstream showroom with order-based delivery from the upstream stock. Moran's I for specialised units on this axis is significantly positive ($p < 0.001$), confirming non-random clustering and validating H2. This binodal structure corresponds to what Remy & Voyé (1974) term the spatial concentration of demand, generating a collective attraction effect that neither node could sustain individually.

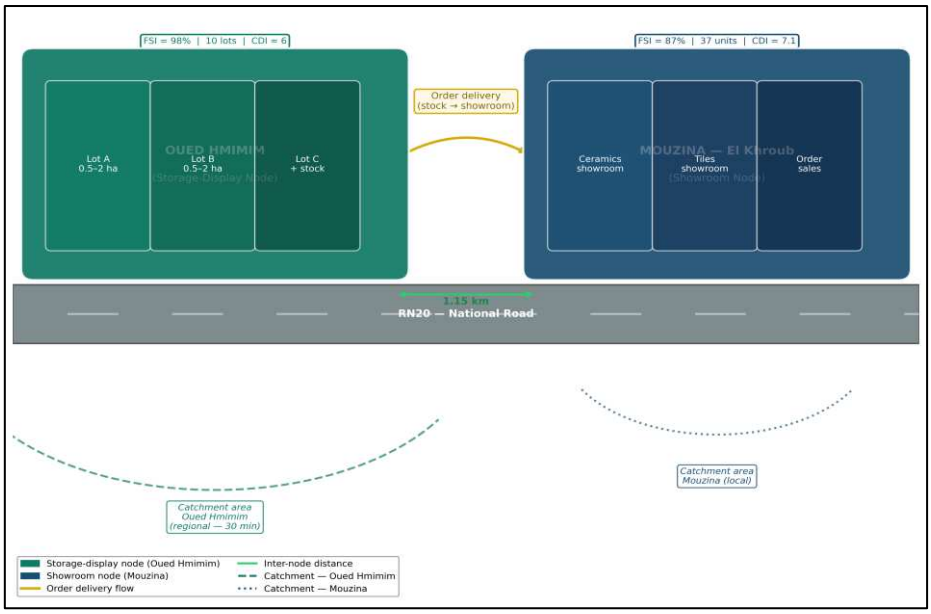


Fig. D2 | Schematic plan of the Oued Hmimim–Mouzina binodal commercial structure (RN20). Left node (teal): storage–display function (FSI = 98%, 10 lots). Right node (navy): showroom function (FSI = 87%, 37 units). Orange arrow: order-based delivery flow from stock to showroom. Green double arrow: inter-node distance (1.15 km). Dashed arcs: differentiated catchment areas (teal: regional 30 min; navy dotted: local). Source: field survey, interviews, authors.

> ▶ *The binodal diagram formalises a logistics architecture that is unprecedented in Berry's original typology: a division of labour between upstream bulk-storage (Oued Hmimim) and downstream customer-facing display (Mouzina) that replicates a supply-chain structure within a linear corridor. This architecture generates two complementary catchment geographies — a regional hinterland (30-min isochrone) oriented towards the storage node, and a more local catchment serving the showroom node — that together cover a substantially larger consumer base than either node alone. The arrow representing order-based delivery flow illustrates the wholesale-logistics function embedded in what is nominally a retail corridor: clients place orders at Mouzina showrooms and take delivery from Oued Hmimim stocks, a mechanism that fully accounts for the 98% FSI and explains the high Moran's I autocorrelation value.*

4.5 Chaaba Rssas (CW175): resource-triggered genesis

Chaaba Rssas (CDI = 19.4; FSI = 77%) exemplifies a genesis pathway entirely absent from Berry's demand-driven model. A surface-water source (seasonal wadi) provided a free input for car washing, which triggered a cascade of affinity agglomeration: mechanics, bodywork, tyres, then building materials. This resource-triggered genesis — supply-push rather than demand-pull — constitutes the second systematic deviation from H3. Located on the Constantine–El Khroub commuting corridor (estimated 15,000–20,000 vehicles/day), Chaaba Rssas also exemplifies Delage's (2012) flow-filter model: its 6 am–10 pm opening hours, roadside visibility and minimal dwell-time design are all calibrated to intercept motorised transit flows.

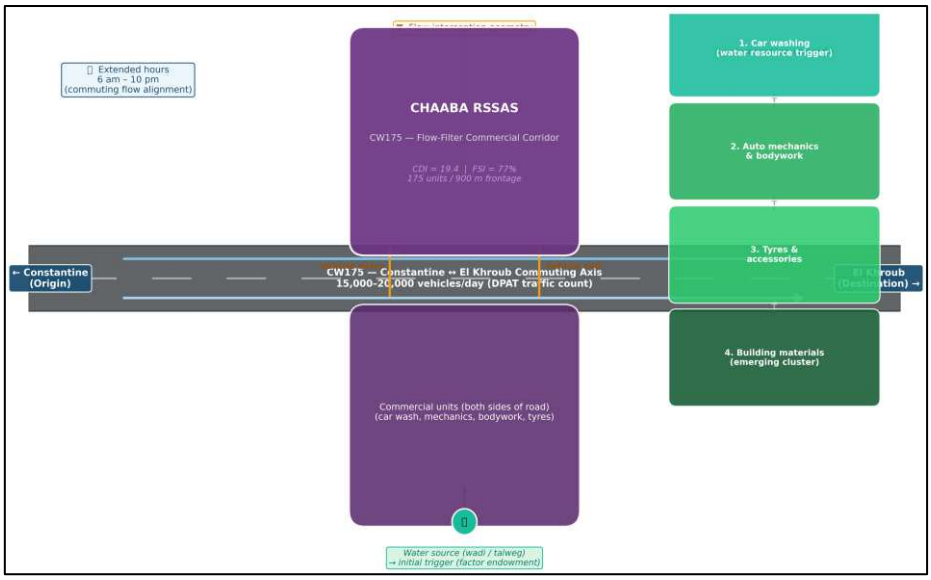


Fig. D3 | Flow-filter commercial model, Chaaba Rssas (CW175). Road band: CW175 commuting axis (15,000–20,000 veh./day). Purple blocks: commercial zone above and below the road. Interception cone (amber): geometric zone of commuter flow capture. Green cascade (right): resource-triggered agglomeration sequence. Teal circle: surface-water source (wadi), initial genesis trigger. Source: field survey, DPAT traffic data, authors.

> ▶ *The flow-filter diagram illustrates a genesis mechanism that inverts the conventional demand-pull logic of commercial location: instead of a pre-existing consumer demand attracting commercial supply, a free natural resource (water) enabled a low-capital activity (car washing) which then generated progressive demand among the captured commuter flow, catalysing successive rounds of agglomeration (mechanics → bodywork → tyres → building materials). This supply-push cascade is consistent with Isard's (1956) general theory of factor-endowment-based localisation and constitutes the empirical core of the HOEC variant's resource-triggered dimension. The interception cone geometry also confirms Delage's (2012) flow-filter model: the commercial zone straddles both sides of the road, maximising exposure to both outbound (morning) and inbound (evening) commuting flows with extended 6 am–10 pm operating hours aligned with the peak traffic pattern documented by the DPAT traffic count.*

4.6 RN05 / RN79: emerging large-format retail

City Mall (RN05) and Magic Market (RN79) represent a qualitatively distinct trajectory: the transition from spontaneous ribbon development to purpose-built highway retail. City Mall, with 12,100 m² of gross building area and 600 parking spaces, embodies the automobile-dependent shopping centre model (Brody, 2013); its late emergence compared to Algiers and Oran reflects the slower pace of Constantine's metropolitan sprawl and the tighter land constraints along national roads. Magic Market constitutes the first multi-storey commercial building meeting the minimum regulatory definition of a shopping centre in the Constantinian metropolitan area.

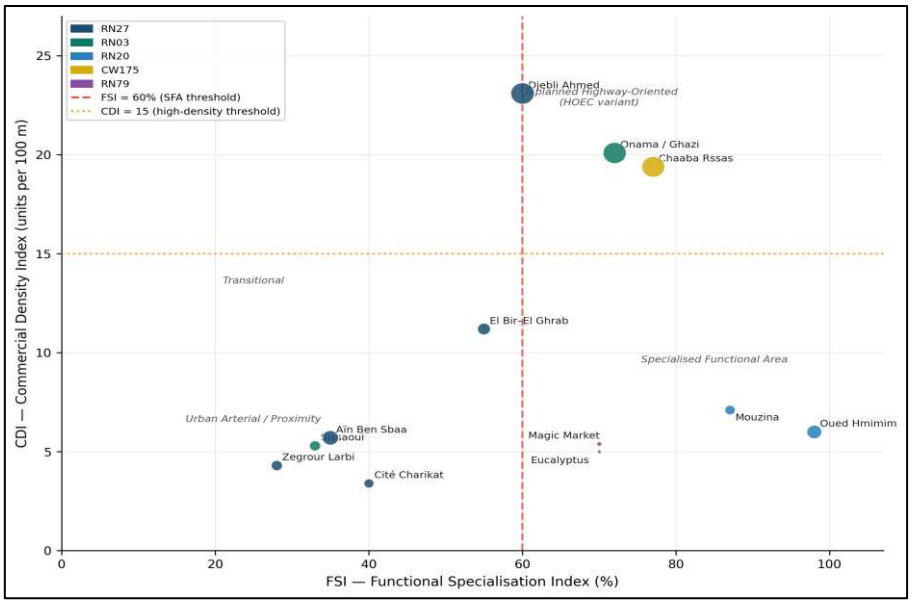


Fig. 7 | Typological matrix: CDI versus FSI (bubble size proportional to unit count per sequence). Red dashed vertical: FSI = 60% (SFA threshold). Amber dotted horizontal: CDI = 15 (high-density threshold). Quadrant labels indicate dominant Berry sub-type or proposed HOEC variant. Source: authors.

▶ *Fig. 7 — The CDI×FSI matrix is the core diagnostic tool of the SMCA protocol, simultaneously representing three commercial dimensions: density (y-axis), specialisation (x-axis) and scale (bubble size). The matrix reveals four inhabited quadrants. The upper-right quadrant (FSI > 60%, CDI > 15) is occupied exclusively by the three HOEC sequences (Djebli Ahmed, Onama/Ghazi, Chaaba Rssas), confirming that the co-occurrence of high density and high specialisation defines the new variant. The lower-right quadrant (FSI > 60%, CDI < 15) contains Oued Hmimim and Mouzina, whose Specialised Functional Area status is driven by mono-specialisation rather than density. The lower-left quadrant contains all proximity and transitional sequences. The upper-left quadrant (high density, low specialisation) is vacant, consistent with the theoretical expectation that high-density commercial corridors require some degree of specialisation to sustain agglomeration externalities. Crucially, bubble sizes confirm that HOEC sequences (Onama/Ghazi, 181 units; Djebli Ahmed, 185 units) are not just the most specialised but also the largest corridors in the sample.*

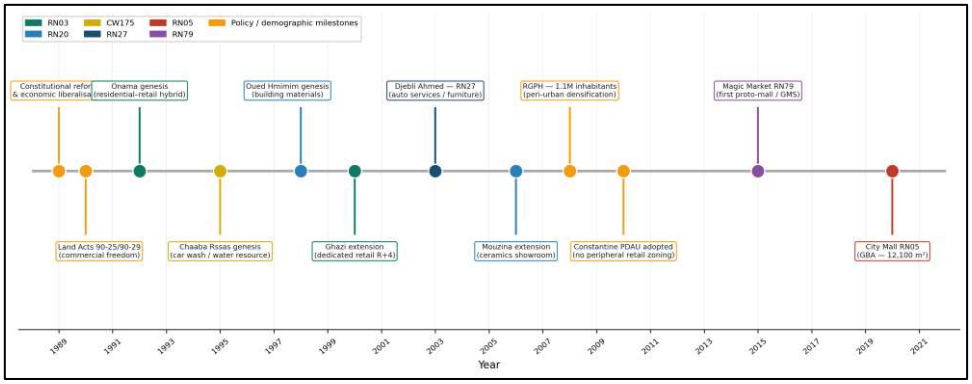


Fig. 8 | Genesis chronology of commercial corridors, 1989–2024. Coloured circles encode corridor identity; amber diamonds indicate regulatory and demographic milestones. Two waves of corridor formation are distinguishable. Source: field interviews, land archives, authors.

▶ *Fig. 8 — The genesis chronology reveals a two-wave model of corridor formation structurally linked to the institutional chronology of post-socialist transition. Wave 1 (1989–2003) was triggered by the combined effect of constitutional liberalisation (1989), Land Acts (1990) and the abrupt opening of import channels: Onama (1992), Chaaba Rssas (1995), Oued Hmimim (1998) and Ghazi (2000) all emerged within this period as opportunistic responses to factor-endowment availability (water for Chaaba Rssas, land for Onama/Ghazi) and import-network access. Wave 2 (2003–2020) was driven by metropolitan sprawl and the growing consumer base of the Constantinian ring: Djebli Ahmed (2003), Mouzina (2006) and the proto-mall formats (Magic Market 2015, City Mall 2020) reflect increasingly demand-driven formation. The systematic time-lag between commercial corridor genesis and regulatory response — the PDAU was adopted in 2010, more than 15 years after the first corridors formed, and contains no peripheral commercial zoning category — is the institutional root cause of the planning vacuum addressed in Section 5.3.*

5. Discussion

5.1 The HOEC variant: extending Berry for post-socialist contexts

The CSI scoring confirms that Constantine's corridors broadly map onto Berry's (1963) New Suburban Ribbon and Unplanned Highway-Oriented types, validating H3's first clause. However, two systematic deviations require a contextual extension. The wholesale–retail integration documented at Onama/Ghazi and Oued Hmimim is not a transitional imperfection but a structural feature of import-driven post-socialist retail: the distinction between wholesale and retail dissolved because liberalisation allowed individual traders to source directly from Yiwu and Istanbul, eliminating the wholesale intermediary (Belguidoum & Pliez, 2012; Kerdoud, 2017). The resource-triggered genesis at Chaaba Rssas is consistent with Isard's (1956) general location theory — where factor endowments shape commercial location — but has no precedent in Berry's North American typology. Together, these deviations define the **Highway-Oriented Enterprise-Centred (HOEC) variant**: a non-planned strip characterised by vertical wholesale–retail integration, import-network embeddedness, and supply-push or resource-triggered genesis.

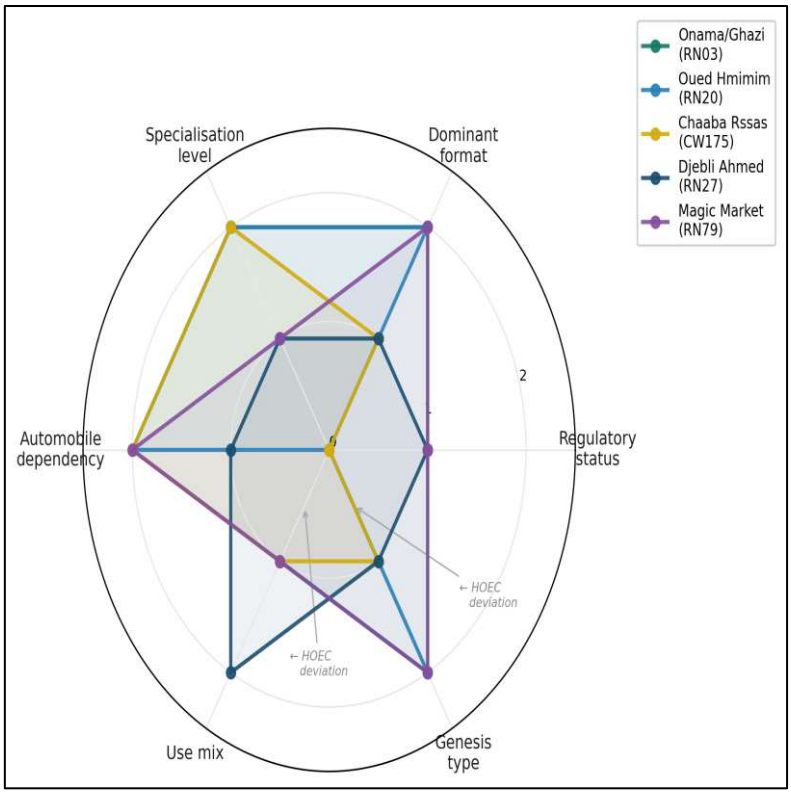


Fig. 9 | CSI radar diagram for five representative corridor sequences. Axes: six Berry-type criteria scored 0–2. Maximum total score: 12 points. HOEC deviations appear as systematic deflections on the 'use mix' and 'genesis type' axes. Source: authors.

> ▶ *Fig. 9 — The CSI radar diagram is the most diagnostic single figure for the HOEC hypothesis. Four observations are critical. First, Onama/Ghazi (dark teal) and Oued Hmimim (blue) both achieve maximum scores (2/2) on the 'specialisation level' and 'automobile dependency' axes, confirming strong correspondence with Berry's Highway-Oriented type on these two canonical dimensions. Second, both sequences, along with Chaaba Rssas, record 0 or 1 on 'regulatory status', reflecting the complete absence of dedicated zoning — a deficiency systematically shared across all HOEC-candidate sequences. Third, the most diagnostic HOEC deflections appear on the 'use mix' axis (0 for Oued Hmimim, 1 for Onama/Ghazi), where the wholesale–retail integration reduces functional diversity below Berry's mono-retail baseline, and on 'genesis type' (1 for Chaaba Rssas vs 2 for demand-driven sequences), capturing the resource-triggered deviance. Finally, Djebli Ahmed*

(navy) presents a markedly different hexagonal profile from the other four sequences, with higher 'use mix' (2/2) and lower 'specialisation level' (1/2), reflecting its transitional character between the HOEC variant and Berry's New Suburban Ribbon type.

5.2 Agglomeration dynamics and the concentration of demand

The self-reinforcing agglomeration hypothesis (H2) is confirmed across all high-FSI sequences: significantly positive Moran's I statistics attest to non-random clustering of specialised units. This finding is consistent with Marshallian externality theory (Marshall, 1890; Fujita & Thisse, 1996), with Remy & Voyé's (1974) spatial demand-concentration concept, and with Atzema et al.'s (2021) recent evidence from Flemish retail networks — suggesting that clustering externalities operate as a trans-contextual mechanism regardless of institutional context. Conversely, low-FSI sequences (Zegrour Larbi, Sissaoui) show no spatial autocorrelation, implying that proximity retail has not reached the critical mass needed to generate self-reinforcing agglomeration. The stark bimodality in both CDI and FSI distributions — a few hyper-specialised dense poles and many residual sequences — mirrors the polarised structure of Constantine's metropolitan mobility network.

5.3 Planning implications: the Peripheral Commercial Activity Zone

The planning vacuum identified by Issad (2019) and Kerdoud (2017) is not incidental but structural: current PDAU and POS instruments lack a dedicated peri-urban commercial zoning category, making it legally impossible to specify setbacks, parking ratios, signage standards or use-mix conditions along national road corridors. This gap is characteristic of post-liberalisation regulatory regimes in the Global South (Gervais-Lambony et al., 2014; Saharaoui & Bada, 2021). The **Peripheral Commercial Activity Zone (PCAZ)** proposed here addresses this gap through three regulatory elements: (a) an explicit wholesale–retail mixed-format provision; (b) setback and parking standards calibrated to national road traffic conditions (standard section: 50–60 m from road boundary); (c) linear specialisation zoning protecting constituted poles from fragmentation by convenience retail intrusion.

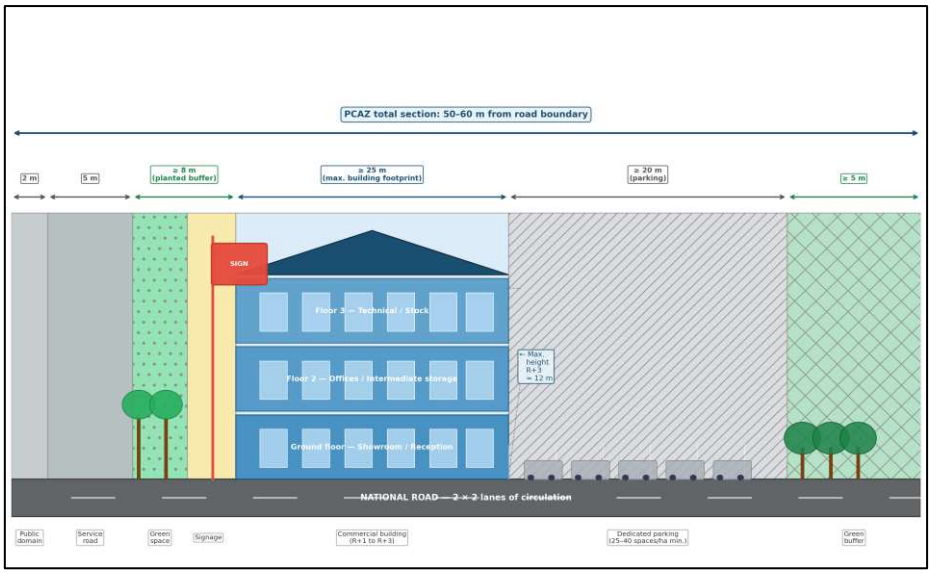


Fig. D4 | PCAZ standard cross-section (50–60 m from road boundary). Components from left to right: pedestrian pavement (≥20 m), service road (5 m), landscaped setback (≥8 m), signage zone (5 m), commercial building R+1 to R+3 (≥25 m footprint; ground floor: showroom), dedicated parking (≥20 m, 25–40 spaces/ha min.), green buffer (≥5 m). Source: authors, based on analysis of the five corridors.

> ▶ *The PCAZ cross-section translates the morphological lessons of the five corridors into a normative planning standard. Four design decisions are grounded in field evidence. The service road (5 m) responds to the flow-filter model: it separates commuter through-traffic from commercial access, reducing the conflict between national-road throughput and commercial parking manoeuvres observed at Chaaba Rssas and Onama/Ghazi. The landscaped setback (≥8 m) internalises the acoustic and visual nuisance mitigation required by residential neighbours documented in the Oued Hmimim area. The R+1 to R+3 height standard accommodates the wholesale–retail hybrid format (ground-floor showroom, upper-floor stock) documented at Onama/Ghazi (R+4), while capping vertical growth to preserve adjacent residential skylines. The dedicated parking standard (25–40 spaces/ha) is calibrated to the automobile-dependency level (CDI = 20.1 at Onama/Ghazi, where parking overflow onto the national road generates safety hazards) documented during the field survey. Together, these standards operationalise a PCAZ category that can be directly inserted into a revised PDAU or POS regulation, filling the zoning vacancy that has left all five corridors without regulatory framework since their formation.*

6. Conclusion

This study has provided the first systematic GPS-georeferenced analysis of unplanned ribbon commercial development in a Maghrebi metropolitan area. Three principal findings stand out. A robust urban–rural specialisation gradient (H1) is empirically confirmed: CDI and FSI decrease monotonically from the urban fringe outward, structuring corridors into three functional zones consistent with a road-deformed Christallerian hierarchy. Strong self-reinforcing agglomeration dynamics (H2) characterise high-FSI clusters, with spatial autocorrelation attesting to non-random unit concentration that cannot be explained by demand density alone. Systematic deviations from Berry's typology (H3) — wholesale–retail vertical integration and resource-triggered genesis — justify the HOEC variant as a contextually grounded extension of the canonical framework.

The SMCA protocol provides a four-phase reproducible framework for corridor analysis in MENA and other Global South contexts where standardised commercial datasets are unavailable. It requires only GPS-referenced field census data, planning documents and key-informant interviews — resources accessible to university research teams across the region. Future research should extend the framework longitudinally to capture corridor evolution over time; test its applicability in Algiers, Oran, Annaba and Sétif, as well as in Moroccan and Tunisian cities that underwent comparable post-liberalisation commercial transformations; and quantify the traffic and environmental externalities of peri-urban ribbon development to inform PCAZ regulatory design.

Data Availability

The GPS-referenced commercial unit database, index calculation spreadsheets and DBSCAN parameter files generated during this study are available from the corresponding author upon reasonable request. Upon acceptance, the dataset will be deposited in the Zenodo open repository (https://zenodo.org).

Code Availability

The Python 3.11 scripts used to compute CDI, FSI, CSI, Spearman ρ, Moran's I and DBSCAN hotspots, and to generate all figures, are available from the corresponding author and will be deposited in a public repository (GitHub or Zenodo) upon acceptance. Key libraries: PySAL 2.7, SciPy 1.11, Matplotlib 3.8, NumPy 1.25, QGIS 3.40.12.

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Author Contributions

[Anonymised for peer review. Author contributions will be declared using CRediT taxonomy upon acceptance.]

Competing Interests

The authors declare no financial or non-financial competing interests.

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Figure Legends

Fig. 1 | Metropolitan road network of Constantine and location of the five commercial corridors studied. Heat intensity on corridors indicates CDI values; red shading signals sequences above the high-density threshold (CDI > 15). Map produced with QGIS 3.28 on OpenStreetMap base data.

Fig. 2 | Spatial distribution of commercial units by sequence represented as proportional symbols. Symbol size is proportional to unit count per sequence. The largest symbols (Onama/Ghazi on RN03 and Djebli Ahmed on RN27, each >180 units) locate at radial–transverse road intersections, consistent with proximity-centrality predictions.

Fig. 3 | CDI and FSI indices by sequence, represented as paired diagrams. Green bars: CDI; brown bars: FSI. The dissociation between CDI and FSI for Oued Hmimim (CDI ≈6, FSI = 98%) illustrates that density and specialisation are orthogonal commercial corridor dimensions.

Fig. 4 | CDI by sequence ranked in descending order. Red dashed line: high-density threshold (CDI = 15 u/100 m). Bar colour encodes corridor identity. Note: City Mall (RN05) excluded as a single GBA building without a linear commercial sequence.

Fig. 5 | FSI by sequence ranked in descending order. Red dashed line: Specialised Functional Area threshold (FSI = 60%). The bimodal distribution (four sequences ≥60%; nine sequences ≤40%) reflects two structurally distinct commercial regimes in the corridor network.

Fig. D1 | Conceptual longitudinal section of the commercial gradient model, parameterised on RN27 empirical data. CDI (solid teal curve, left axis) and FSI (dashed navy, right axis) both follow exponential decay from the urban fringe. Coloured bands indicate the three functional zones of the tripartite gradient model.

Fig. 6 | CDI (circles, left axis) and FSI (squares, right axis) plotted against distance from the urban fringe along the RN27 corridor. Shaded bands: three functional zones. Dashed lines: linear regression fits. Spearman rank correlations reported in the annotated box.

Fig. D2 | Schematic plan of the Oued Hmimim–Mouzina binodal commercial structure (RN20). Node colours encode function: teal = storage–display (FSI = 98%); navy = showroom (FSI = 87%). Orange arrow: order-based delivery flow. Arcs: differentiated catchment areas.

Fig. D3 | Flow-filter commercial model for Chaaba Rssas (CW175). The interception cone indicates the spatial geometry of commuter-flow capture. The green cascade illustrates the resource-triggered agglomeration sequence: water source → car washing → auto mechanics → tyres → building materials.

Fig. 7 | CDI versus FSI typological matrix. Bubble size proportional to unit count. Red dashed vertical: FSI = 60% (SFA threshold); amber dotted horizontal: CDI = 15 (high-density threshold). Quadrant labels indicate the dominant Berry sub-type or the HOEC variant.

Fig. 8 | Genesis chronology of commercial corridors (1989–2024). Coloured circles encode corridors; amber diamonds mark regulatory and demographic milestones. Wave 1 (1989–2003) and Wave 2 (2003–2020) are distinguishable.

Fig. 9 | CSI radar diagram for five representative corridor sequences. Six axes scored 0–2 per Berry-type criterion (max. 12 points). HOEC deviations materialise as systematic deflections on the 'use mix' and 'genesis type' axes across all three HOEC sequences.

Fig. D4 | PCAZ standard cross-section (50–60 m from road boundary). Components: pedestrian pavement, service road, landscaped setback, signage zone, commercial building R+1–R+3, dedicated parking, green buffer. Standards are calibrated to the morphological evidence from the five corridors.

Tables

Table 1 | SMCA protocol: indices, formulae and interpretation thresholds.

Indicator	Formula / definition	Threshold / interpretation
CDI — Commercial Density Index	CDI = n / L × 100 (units / 100 m)	≤5: low | 5–15: medium | >15: high
FSI — Functional Specialisation Index	FSI = n_spec. / n_total × 100 (%)	Threshold: ≥60 % = Specialised Functional Area
Commercial gradient	Spearman ρ (FSI vs. distance from fringe)	ρ < −0.6, p < 0.05: significant negative gradient
CSI — Correspondence Score Index	6 criteria × [0–2] = max. 12 pts	8–12: strong match | <4: divergence
Moran's I (global)	Spatial autocorrelation (PySAL)	I > 0, p < 0.05: significant non-random clustering
DBSCAN	ε = 200 m, minPts = 5	Delineates high-density commercial clusters

[1] *Specialised Functional Area threshold of 60% per Berry (1963). Source: authors.*

Table 2 | Corridor synthesis: sequences, CDI, FSI and Berry sub-type.

Corridor	Sequence	L (m)	N units	CDI	FSI (%)	Dominant specialisation	Berry sub-type
RN27	El Bir–El Ghrab	500	56	11.2	55%	Construction / auto services	New Suburban Ribbon
RN27	Djebli Ahmed	800	185	23.1★	60%	Auto services / furniture	New Suburban Ribbon
RN27	Cité Charikat	1,000	34	3.4	40%	Mixed / auto	Urban Arterial
RN27	Aïn Ben Sbaa	1,500	86	5.7	35%	Agricultural / rural supply	Transitional
RN27	Zegrour Larbi	1,000	43	4.3	<30%	Convenience / proximity	Transitional
RN03	Onama / Ghazi	900	181	20.1★	72%●	Furniture / electronics	Highway-Oriented (HOEC)†
RN03	Sissaoui	800	42	5.3	33%	Mixed convenience	New Suburban Ribbon
RN20	Oued Hmimim	900	15 lots	~6	98%●	Building materials	Specialised Functional Area
RN20	Mouzina	520	37	7.1	87%●	Ceramics / construction	Specialised Functional Area
CW175	Chaaba Rssas	900	175	19.4★	77%●	Automotive services	Highway-Oriented (HOEC)†
RN05	City Mall	—	1 (GBA)	—	—	Shopping centre / GMS	Planned Hwy-Oriented
RN79	Magic Market	166	9	5.4	~70%●	Mixed retail	Proto-mall (emerging)
RN79	Eucalyptus	106	6	5.0	70%●	Hybrid convenience	Highway-Oriented (HOEC)†

★ *CDI > 15 (high density).* ● *FSI ≥60% (Specialised Functional Area).* † *HOEC = Highway-Oriented Enterprise-Centred variant (see Section 5.1). Source: GPS field census, authors.*