Inclusive Urban Planning Based on Time-Use Analysis: A Markov Chain Approach Across Family Life Cycles

Jing Guo, De Wang[1]
College of Architecture and Urban Planning, Tongji University, Shanghai 200092, China
dewang@tongjiçedu.cn
Corresponding Author: Email: dewang@tongji.edu.cn

Abstract
As China's urbanization shifts from rapid expansion to quality-oriented development, understanding the dynamics of time use across different stages of the family life cycle is essential for designing more inclusive and targeted urban planning strategies. Time, as a key indicator of quality of life, is profoundly influenced by family structure, social roles, and the living environment. However, existing studies on time pressure and behavioral dynamics lack a systematic life-cycle perspective. Drawing on the 2018 Shanghai time-use survey, this study identifies weekday activity structures and high time-pressure periods across typical life stages and applies a Markov chain model to construct activity-state transition matrices. Through this, we uncover critical spatiotemporal stress points at each stage and propose planning strategies for inclusive cities. Key findings include: (1) Time-use patterns evolve from a "work-oriented" structure to a more complex "care–work–leisure" interplay as families progress through life stages, with the childcare phase showing the most acute time pressure. (2) Entropy-based fragmentation metrics highlight morning and evening peaks as the most stressful periods. (3) Markov models reveal frequent activity transitions within these pressure zones: work-centric paths dominate during the pre-nesting phase; dual cores of employment and family responsibilities emerge during the nesting phase; childcare years exhibit the most complex and fragmented chains; post-child phases shift toward work and leisure; and the dissolution phase focuses on health care and rest. (4) Based on these insights, we propose differentiated spatial strategies aligned with family life cycles, including nighttime leisure facilities, parenting support spaces, and age-friendly infrastructure. This research contributes to a deeper understanding of dynamic time-space behaviors and offers data-driven insights for building age-inclusive and socially equitable cities.

Keywords: Time use; Family life cycle; Markov chain; Time pressure; Inclusive urban planning

0. Introduction

Identifying differences in residents' time use across various life stages is crucial for advancing inclusive urban planning. Time is not only a constraint on daily activity participation but also a central indicator of quality of life and lifestyle (Jiao & Wang, 2021). With the advancement of activity-based approaches, spatiotemporal behavior research has deepened, and concepts such as time-space prisms and potential path areas have provided a theoretical foundation for linking time use with life quality.

The family life cycle offers a critical perspective for understanding the evolving stages of family development, encompassing processes such as marriage, childbearing, child-rearing, children leaving home, and elder care (Wang & Liu, 2024). In recent years, China's family structures have become increasingly diverse, with a rise in aging populations, nuclear families, and empty-nest households, accompanied by a continuous restructuring of internal family roles. In Shanghai, for instance, people aged 60 and above make up 23.4% of the population, and grandparents are responsible for 31.7% of childcare for children aged 0–3 (Ma et al., 2023), highlighting the prevalence of "active aging." At the same time, young adults face challenges such as flexible employment and economic dependence on parents(Wang, 2024), with intensified workloads and parenting responsibilities leading to time poverty and declining life satisfaction (Jiao et al., 2023).

While prior research has addressed the impacts of aging, family transformation, and employment pressures on well-being, systematic time-use studies from a family life cycle perspective remain limited. This gap constrains our understanding of the mechanisms behind quality of life and hinders the formulation of evidence-based urban policies.

This study draws on the 2018 Shanghai residents' time-use survey to classify five stages of the family life cycle and extract twelve major categories of daily activities. It summarizes time-use patterns across life stages, identifies high time-pressure periods using fragmentation entropy, and applies a Markov chain model to extract

typical behavior transition pathways. By uncovering the distinctive time-pressure characteristics and behavioral mechanisms of each life stage, the study offers targeted recommendations for inclusive urban planning.

1. Literature Review

The family life cycle is a theoretical concept that describes the developmental stages a family undergoes from formation to dissolution. First introduced by sociologists Sorokin, Zimmermann, and Galpin in 1931, the framework outlines key life events such as marriage, childbirth, children leaving home, and the death of family members (Sorokin et al., 1931). Building on this foundation, Paul C. Glick (1947) proposed a more systematic classification, dividing the family life cycle into the formation, expansion, stability, contraction, empty-nest, and dissolution stages—each corresponding to critical family milestones like marriage, child-rearing, children becoming independent, and spousal loss (Glick, 1955). This framework has proven valuable for understanding evolving family needs and behavioral shifts across stages, and it has been widely applied in sociology, economics, demography, and urban planning.

In recent years, scholars have localized and refined the family life cycle theory to better reflect China's social realities. For example, Guo Jingjing and Chai Yanwei (2014) examined suburban residents' lifestyles and leisure preferences, emphasizing how leisure activity types and time allocation vary by life stage. Du Xiaojuan et al. (2017) further subdivided the "full nest" phase into distinct stages such as infancy, preschool, school age, and adult children, offering a more nuanced view of parenting-related transitions, particularly in consumption preferences and shopping behavior. Mao Yaqian and Li Jiuquan (2020) focused on the elderly and multigenerational households, identifying diverse living arrangements such as empty-nest single living and co-residence with children. Their work expanded the applicability of the life cycle framework by incorporating the perspective of intergenerational family support.

The family life cycle not only shapes individual behavior but also deeply influences urban spatial practices. Research shows that life stages significantly affect housing decisions (Pan, 2024), spatial settlement preferences among migrant populations (Yang et al., 2024), and willingness to participate in the renewal of aging neighborhoods (Xiao et al., 2022). Thus, detailed segmentation of the life cycle offers critical insights into understanding modern household spatial needs, aligning urban services, and informing policy interventions. In particular, it serves as a guiding framework for inclusive urban planning and housing policy in the face of population aging and increasing multigenerational living arrangements.

Time Use Surveys (TUS) serve as high-resolution tools for recording individuals' daily activities and time allocation. Now conducted in over 100 countries worldwide, TUS data are widely applied across disciplines such as sociology, economics, gender studies, and the built environment (Osman & Ouf, 2021). A time use pattern refers to the structure of activity types, sequences, and time distribution over a given period, encompassing key life dimensions such as work, domestic chores, leisure, and commuting (Song et al., 2023). These behavioral patterns involve both static attributes—such as activity type, location, and social role—and dynamic temporal sequences.

In recent years, growing attention has been paid to the relationship between individual time use and subjective well-being. For instance, Zhao Hong (2023), using China's 2017 national TUS data, estimated that the "optimal work duration" for employees is 6.25 hours per day. Similarly, Jiao Jian et al. (2023) introduced a "time poverty" threshold, defining it as 60% of the median free time, and suggested that workers in Shanghai should have at least 2.72 hours of discretionary time daily.

Amid the twin challenges of population aging and digitalization, researchers have also focused on time-use patterns among specific groups. These include studies on older adults' travel time (Sen et al., 2022), sedentary behavior (Perchoux et al., 2023), and the use of leisure and screen time (Sturm & Cohen, 2019). Such research is increasingly important for identifying disparities in life satisfaction and addressing equity in public service provision, particularly for vulnerable populations.

From the perspective of dynamic behavioral modeling, the Markov Chain has become a widely used tool in studies of life cycle, health, employment, and mobility due to its structural capability to model state transitions (Xia et al., 2023). Its foundational assumption of "memorylessness"—where the probability of transitioning to the next state depends solely on the current state—makes it ideal for modeling evolving behavioral trajectories. In the context of family studies, Han et al. (2020) applied Markov models to explore pathways of family structure evolution, identifying typical transition chains and influencing factors between different life stages. When integrated with time use data, Markov Chain models can be used to construct activity time sequences and capture the structural dynamics of daily behaviors, thereby offering quantitative insight into how families reallocate time and adjust behaviors over the course of the life cycle.

Based on this foundation, the present study adopts the following analytical framework (Figure 1). First, using 2018 Shanghai TUS data, we focus on residents' time use during workdays and summarize time-use patterns across different stages of the family life cycle. Second, we apply entropy-based fragmentation metrics to identify high time-pressure periods for each stage. Third, using these high-pressure intervals as analytical windows, we calculate transition probability matrices via the Markov Chain model to reveal the most frequent activity shifts for each life cycle stage. Finally, we propose differentiated strategies for optimizing time-space resource allocation tailored to the unique spatiotemporal challenges of each stage.

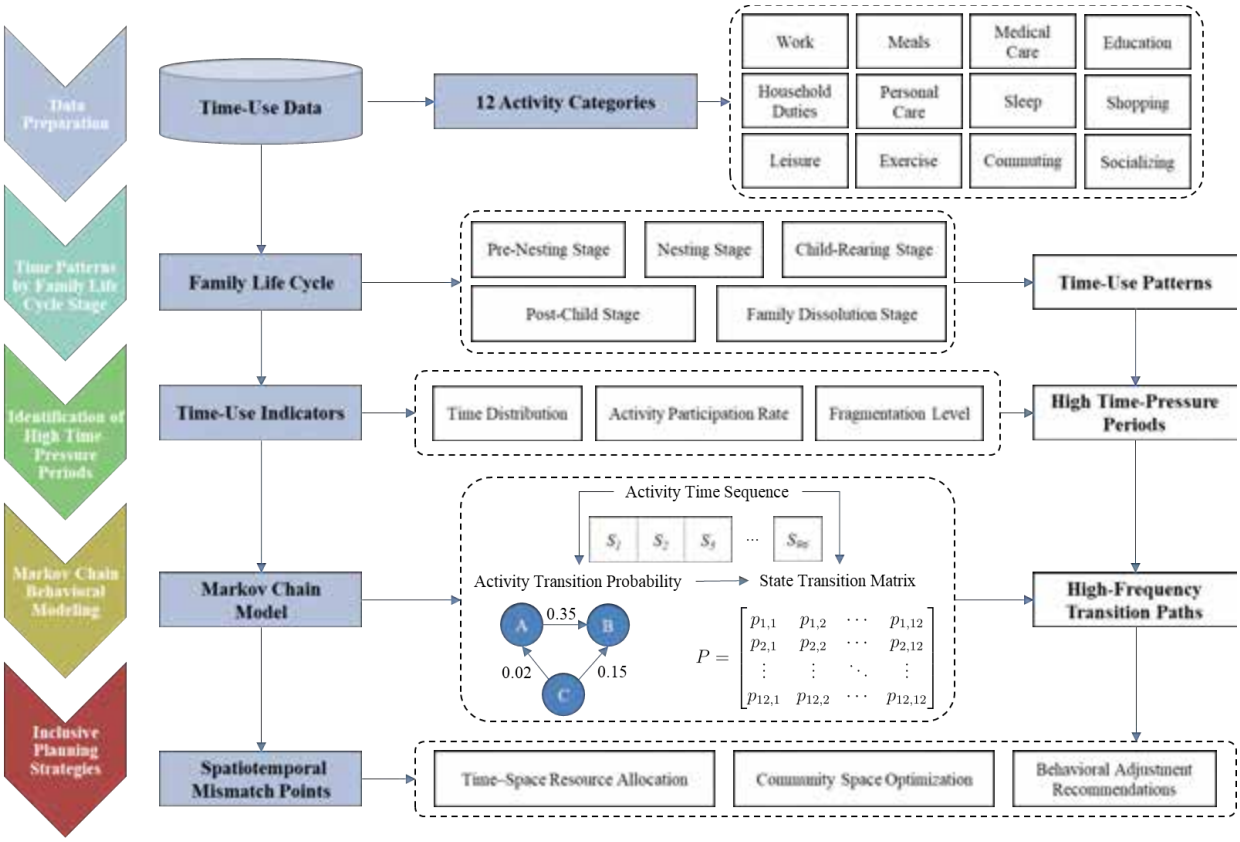

Figure 1. Technical Framework of the Study

2. Research Data and Methods

2.1 Time-Use Data

This study draws on data from the 2018 Shanghai Time Use Survey, which employed a stratified sampling approach and collected responses from 1,351 households, comprising a total of 3,297 individual samples. The survey captured comprehensive information on individual demographics, household composition, and time-use behaviors, documenting specific activities in 15-minute intervals over the course of a single day.

The raw data were cleaned and standardized, with all time entries converted into 96 uniform 15-minute segments per day to form a continuous time series. To simplify the analysis, 48 original detailed activity categories were consolidated into 12 broader activity types (Table 1). These categories represent the individual's activity status at each time point and serve as the basis for constructing the Markov transition model in subsequent stages of the research.

Table 1. Classification of Time-Use Activity Types

Category	Included Activities
Work	Full-Time Work, Part-Time Work, Agricultural Work, Non-Agricultural Business, Job Training, Vocational Training, Job Search
Household Duties	Household Management, Caregiving, Daily Care, Child Pick-Up/Drop-Off, Laundry and Cleaning, Cooking, Pet Care, Playing With Children
Leisure	Tea Drinking, Fishing, Board Games, Cultural and Media Activities, Web Browsing, Arts, Tourism, Smoking
Meals	Breakfast, Lunch, Dinner, Other Eating Activities
Personal Care	Grooming, Washing, Using the Restroom
Exercise	Fitness Training, Health Management
Medical Care	Medical Treatment, Doctor Visits, Accompanying Someone to The Doctor, Beauty Services
Sleep	Night Sleep, Rest Breaks, Naps
Commuting	Personal Transportation
Education	Formal Education, Adult Education, Homework, Tutoring, Waiting for Classes, Internships
Shopping	Buying Goods, Purchasing Services
Socializing	Social Visits, Companionship, Conversations, Volunteer Work

2.2 Classification of Family Life Cycle Stages

To systematically analyze structural differences in time-use patterns across life cycle stages, this study develops a tailored classification framework (Table 2), drawing on demographic and sociological theories of the family life cycle and incorporating the lived realities of Shanghai residents.

The classification is based on both the logical progression of household development and the intergenerational composition of family members. On one hand, five primary stages are defined according to changes in household structure and role transitions: Pre-Nesting, Nesting, Child-Rearing, Post-Child, and Family Dissolution. On the other hand, to reflect generational composition, the Child-Rearing stage is further divided into two subtypes: Nuclear Families (households composed of only parents and their children) and Multigenerational Families (households where three or more generations live together).

Table 2. Family Life Cycle Stage Statistics

Family Life Cycle Stage	Stage Description	Households
Pre-Nesting	Adult individuals who are single, unmarried, and childless, living independently. They have minimal family responsibilities, with daily activities centered around work and personal routines.	N = 105
Nesting	Married or cohabiting couples without children. These households are in stable partnerships, take on limited domestic responsibilities, and are not yet engaged in childrearing.	N = 127
Child-Rearing	Households with children aged 0–18 or grandparents caring for grandchildren in the same age range. Includes both nuclear and multigenerational families. Typically face heavy caregiving and domestic responsibilities.	N = 406
Post-Child	Households where children have reached adulthood or are attending university (18+), but still reside with parents or grandparents. While caregiving burdens are reduced, intergenerational cohabitation requires continued resource and space coordination.	N = 208
Family Dissolution	Households where children have fully left home, or where the family structure has undergone reorganization (e.g., divorce, widowhood, empty nest). These households are typically composed of older adults or grandparents living with adult children. Time autonomy is high, but issues such as health concerns, loneliness, or spatial mismatch may arise.	N = 505

2.3 Markov Chain Model

2.3.1 Time Distribution and State Definition

On the temporal dimension, each 24-hour workday is divided into 96 discrete time intervals, each representing a 15-minute segment. For each interval, the individual's primary activity is recorded and treated as a discrete state, denoted as S_t. This produces a daily activity-state sequence of length 96 for each individual:

$$\{S_1, S_2, \ldots, S_{96}\}$$

According to the classification system outlined in Table 1, all activities are grouped into 12 major categories. Each category is defined as a unique state, forming the complete set of possible activity states:

$$S=\{S_1, S_2, \ldots, S_{12}\}$$

This state set captures the primary behavioral types that make up residents' daily routines and serves as the foundation for the subsequent Markov chain-based behavioral modeling.

2.3.2 Activity Participation Rate

At the aggregate level, to assess the prevalence and temporal patterns of different activity types across family life cycle stages, this study introduces the indicator of activity participation rate. This metric reflects the proportion of individuals engaged in a specific activity during a given time interval, relative to the total sample size at that time. It is used to identify the temporal concentration and peak periods of particular behaviors.

The participation rate is calculated using the following formula:

$$P_{a,t} = \frac{N_{a,t}}{N_t} \times 100\%$$

Where: $P_{a,t}$ represents the participation rate of activity a at time t; $N_{a,t}$ is the number of individuals engaged in activity a during that time interval; and N_t is the total number of individuals in the sample at time t.

2.3.3 Fragmentation Entropy Calculation

During periods characterized by frequent transitions between activity states, individuals are more likely to experience elevated time pressure. To capture the degree of time-use fragmentation, this study employs the Shannon entropy index. Based on each individual's full-day activity sequence, the proportion of time spent on each activity category is calculated, and the corresponding fragmentation entropy is computed as follows:

$$H = -\sum_{i=1}^{n} p_i \log_2 p_i$$

Where: p_i represents the proportion of total daily time spent on activity category i, and $n = 12$ is the total number of activity categories. A higher fragmentation entropy indicates that the individual engages in a greater variety of activities, with more frequent transitions and a more dispersed time distribution throughout the day.

In addition, this study also calculates group-level fragmentation entropy at each time point. Specifically, for a given life cycle stage, the activity distribution $p_i(t)$ across all individuals during a specific time interval is used to compute the Shannon entropy. This value reflects the behavioral diversity of the group at that particular moment in time.

2.3.4 Identification of High Time-Pressure Periods

By plotting the average fragmentation entropy curve across the 96 daily time intervals for each family life cycle stage, this study identifies periods marked by sharp increases in entropy and significant behavioral diversity. These intervals are defined as high time-pressure periods. Such periods often correspond to peak commuting hours or times when multiple household responsibilities converge, characterized by frequent activity switching and heightened time constraints.

2.3.5 Markov Modeling and Transition Matrix Construction

After identifying the high time-pressure periods, the activity-state sequences of individuals within these intervals are extracted for each family life cycle stage. A first-order discrete-time Markov chain model is then constructed, where the state transition is defined as follows:

$$P(S_{t+1} = j \mid S_t = i) = p_{ij}$$

Where: p_{ij} represents the probability that an individual currently in state *i* transitions to state *j* in the next time interval. For each family life cycle stage, all observed transitions during the high time-pressure periods are aggregated and normalized to construct the state transition probability matrix:

$$P = \begin{bmatrix} p_{1,1} & p_{1,2} & \cdots & p_{1,12} \\ p_{2,1} & p_{2,2} & \cdots & p_{2,12} \\ \vdots & \vdots & \ddots & \vdots \\ p_{12,1} & p_{12,2} & \cdots & p_{12,12} \end{bmatrix}$$

This matrix captures the internal structure of behavioral switching within each life cycle stage. It serves as the basis for identifying typical high-frequency behavioral pathways and uncovering structural differences in time allocation and daily rhythms across different family types.

3. Time-Use Patterns Across Family Life Cycle Stages

3.1 Weekday Time Allocation in Representative Family Life Cycle Stages

The time-use survey data clearly illustrate the full-day structure of individual schedules, patterns of household division of labor, and spatial activity chains. Representative households from each family life cycle stage were selected from the sample, and 24-hour weekday activity timelines were constructed for all household members (Figure 2).

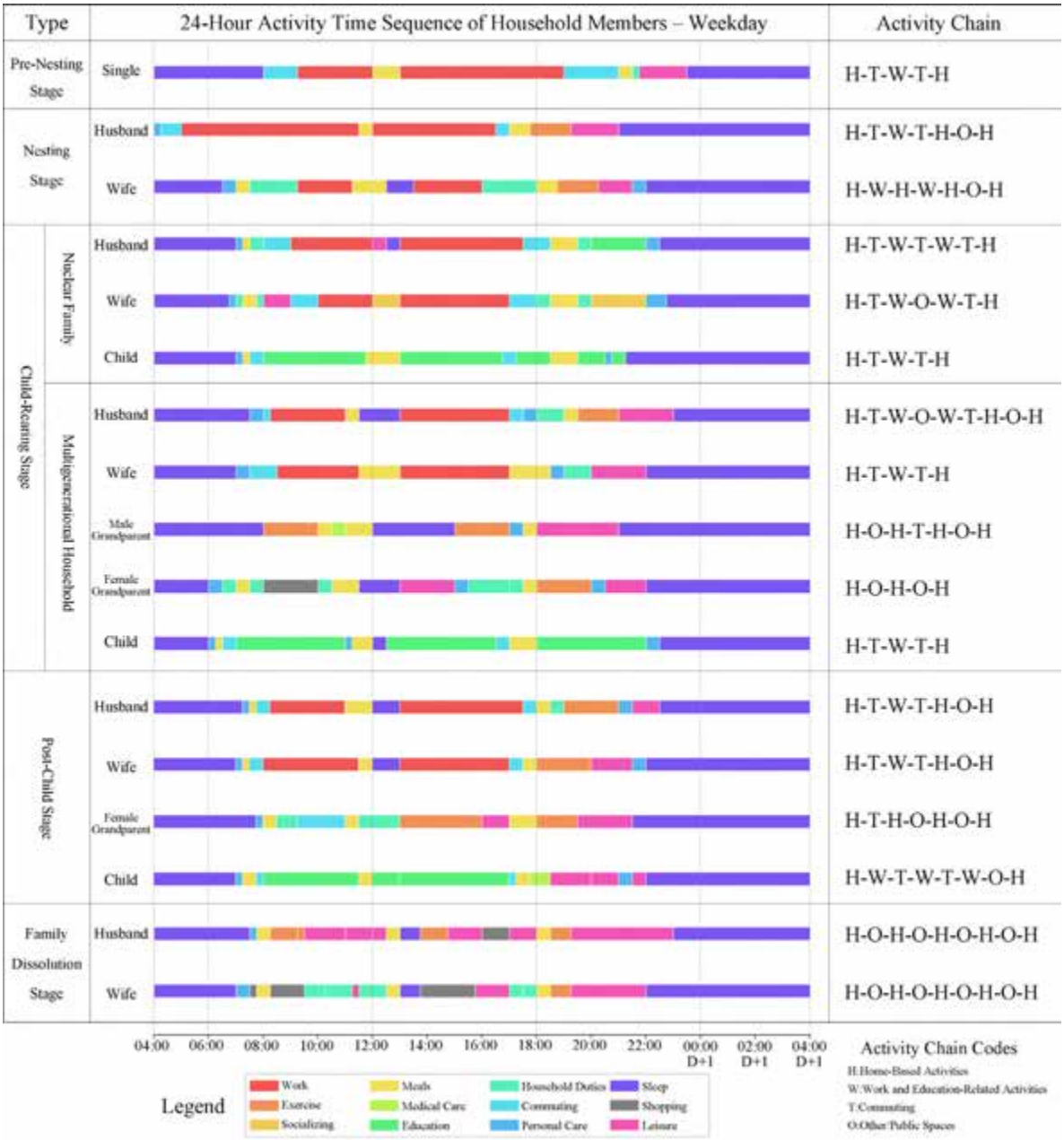

Figure 2. Time-Use Distribution on Workdays Across Typical Family Life Cycle Stages

1. Pre-Nesting Stage: The household consists of a single adult male or female. The daily activity pattern follows a streamlined "Work–Commute–Leisure–Sleep" cycle. The activity chain is highly simplified, with strong personal control over time and no interference from household responsibilities, reflecting a typical pattern of autonomous time use.

2. Nesting Stage: The household is composed of a husband and wife, both primarily engaged in professional work, with generally synchronized daily rhythms. In addition to the basic commute–work loop, their activity chains include connections to non-residential spaces such as commercial areas or fitness facilities, reflecting expanded engagement in leisure and personal services. The wife assumes household responsibilities before and after meals, indicating the early formation of an internal division of labor.

3. Child-Rearing Stage (Nuclear Family): Both the husband and wife maintain work-centered schedules, but with additional responsibilities related to caregiving and education, reflecting the time pressure experienced by dual-earner households balancing employment and parenting. Children follow a "Study–Rest" structure.

Child-Rearing Stage (Multigenerational Family): Compared to nuclear households, some caregiving responsibilities are shared with grandparents. These older family members typically follow short-loop activity chains (e.g., Home–Outside–Home), centered around shopping, caregiving, and meal preparation, thus providing auxiliary parenting support. As a result, both the husband and wife enjoy more leisure time than in nuclear families. Children still follow a study-oriented routine, forming a clear model of intergenerational division of labor and cooperative caregiving.

4. Post-Child Stage: The husband and wife continue to work, while their children are in college. Household caregiving demands are significantly reduced, with noticeable increases in time spent on fitness and leisure activities. Their activity chain shifts from the previously intense "Commute–Work–Caregiving" mode to a more relaxed "Work–Leisure/Fitness" structure.

5. Family Dissolution Stage: Most household members are empty-nest elderly individuals. Daily routines center around non-work activities such as leisure, exercise, and shopping. The activity chain is highly flexible with minimal repetition, and the time structure is loose, indicating a high degree of autonomy and a lifestyle characterized by "non-commuting, non-working" patterns.

3.2 Time-Use Patterns Across Family Life Cycle Stages

Figure 3 presents the average weekday duration of each activity category across the five family life cycle stages, highlighting the overall influence of life stage on time-use patterns—particularly in the allocation of time to work, household duties, and leisure.

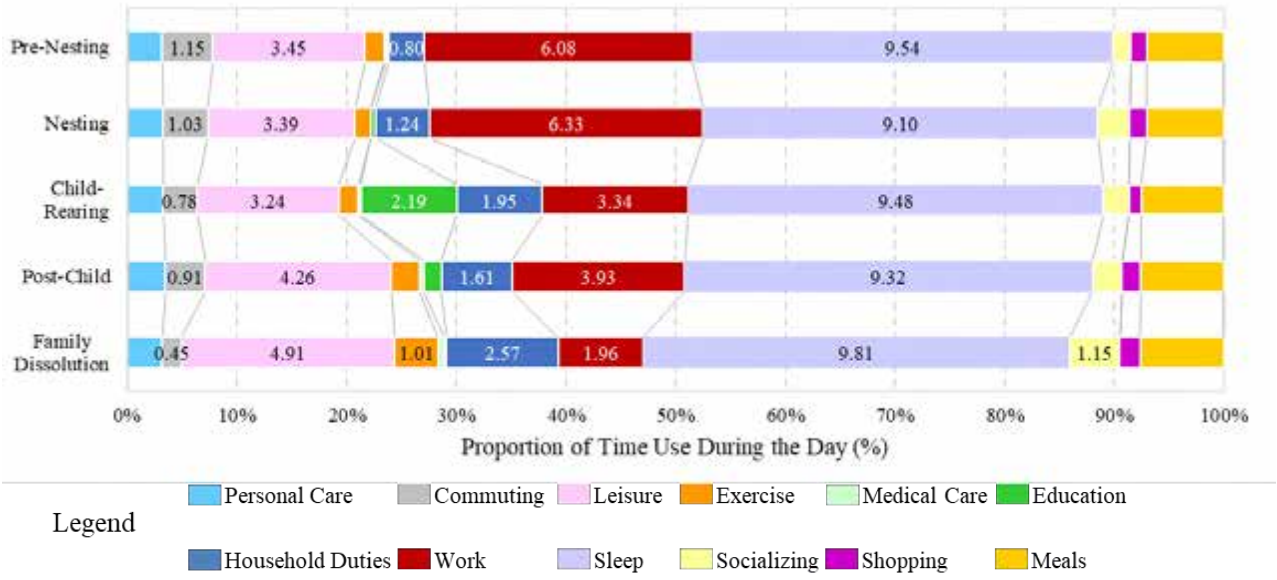

Figure 3. Average Daily Activity Duration by Family Life Cycle Stage

First, work hours exhibit an overall inverted U-shaped pattern. During the career-intensive stages of the Pre-Nesting and Nesting phases, average work durations reach 6.08 and 6.33 hours per day (h/d), respectively. As families enter the Child-Rearing stage, work time becomes compressed due to increased caregiving responsibilities, though both husbands and wives continue to spend substantial time working. In the Post-Child and Family Dissolution stages, work duration gradually declines to 3.93 h/d and 1.96 h/d, respectively—reflecting a restructuring of daily schedules in the context of retirement.

Second, household responsibilities and educational activities peak during the Child-Rearing stage. Individuals in this stage spend an average of 2.19 h/d on education-related tasks and 1.95 h/d on household duties—significantly higher than in any other life stage. This suggests that family members are simultaneously managing both caregiving and educational support, making it one of the most time-pressured phases of the life cycle.

Third, leisure and physical exercise time increases at both ends of the life cycle. Residents in the Pre-Nesting, Post-Child, and Family Dissolution stages each report more than 3.4 h/d of leisure time. In the Family Dissolution stage specifically, individuals also spend about 1 h/d on exercise and socializing, resulting in nearly twice as much discretionary time as those in the Child-Rearing stage. This shift reflects greater time autonomy and a slower, more flexible daily rhythm.

In contrast, sleep duration remains stable across all life stages, with average sleep time exceeding 9 h/d in each category. This consistency underscores sleep as a basic physiological necessity, largely unaffected by changes in life stage.

Finally, commuting time is most prominent during the Pre-Nesting, Nesting, and Child-Rearing stages, indicating that commuting is closely tied to employment. The time squeeze becomes especially acute when individuals must balance full-time work with active parenting responsibilities.

Further, Figure 4 illustrates the full-day activity participation rates on weekdays across the five family life cycle stages, revealing the stage-specific influence of family life progression on individual time rhythms and allocation patterns.

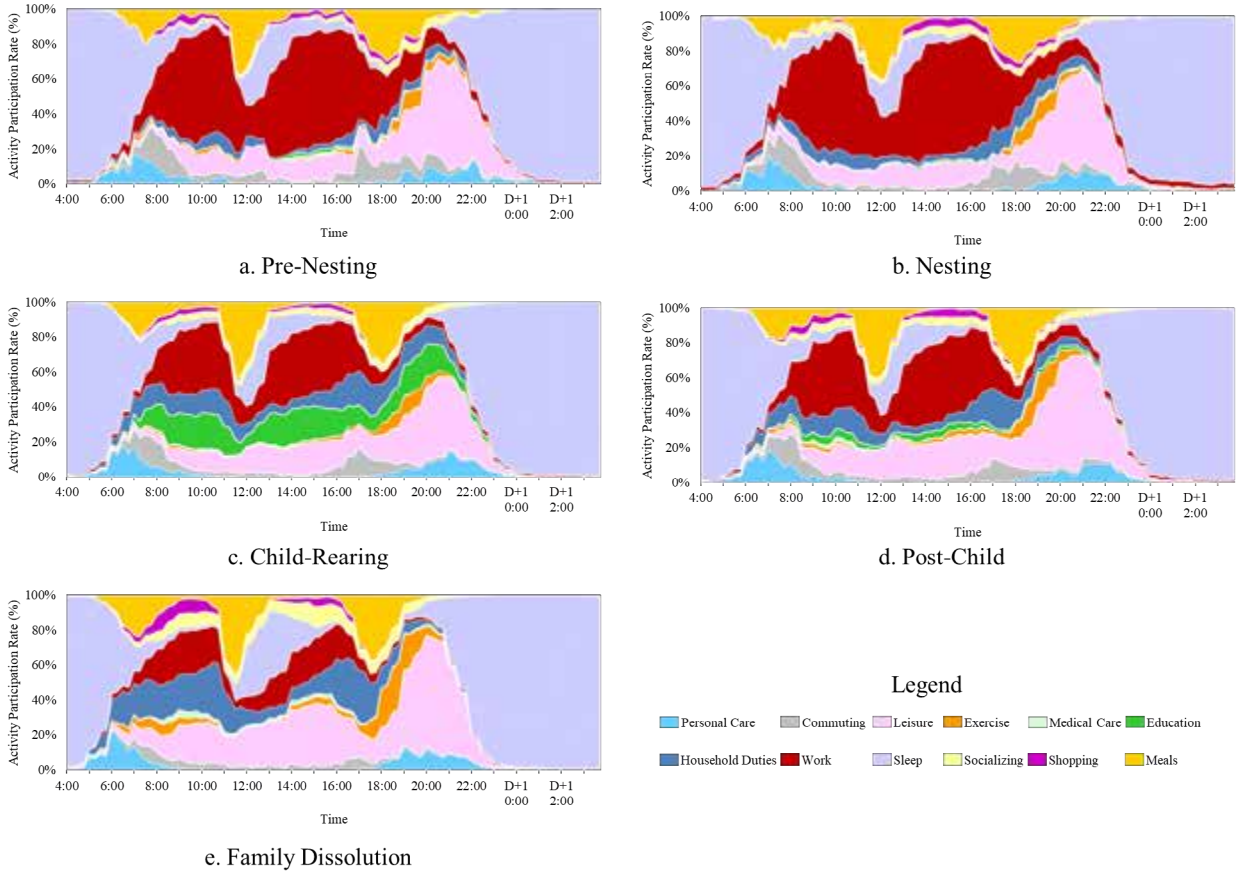

Figure 4. Activity Participation Rates Throughout the Day by Family Life Cycle Stage

1. Pre-Nesting Stage: Time-use rhythms are highly concentrated and autonomous. Work-related activities form a clear double peak between 9:00–12:00 and 14:00–18:00, while commuting peaks appear around 8:00 and 18:00, reflecting an intensive "commute–work" cycle. After 19:00, leisure becomes dominant—particularly virtual forms of leisure—with participation rates approaching 60%, indicating a high level of temporal freedom.

2. Nesting Stage: Daily rhythms are strongly work-centered, exhibiting clear synchronization between partners and emerging patterns of household coordination. Work participation remains high from 9:00 to 17:00, with pronounced commuting peaks that slightly extend earlier and later than in the Pre-Nesting stage. Participation in household duties, shopping, and exercise rises during early morning and evening hours, suggesting the early formation of internal role division and shared domestic routines.

3. Child-Rearing Stage: This stage shows the most complex distribution of activities, with a fragmented time-use pattern driven by the interplay of employment and caregiving. Work and educational activities remain high between 9:00 and 17:00, while commuting peaks occur from 7:00–8:00 and 16:30–17:30. Household duties and meals are concentrated in the morning, midday, and evening, highlighting the pressure of managing multiple roles—work, caregiving, and domestic tasks. In multigenerational households, grandparents also participate in household responsibilities and shopping during morning and afternoon hours. Leisure and exercise are mostly confined to nighttime, often squeezed out by other obligations.

4. Post-Child Stage: Daily activities shift toward leisure and personal development. While employed household members continue to follow standard work routines, work and commuting participation rates decline compared to the Nesting stage. Participation in leisure, exercise, and social activities increases significantly, indicating a growing emphasis on quality of life outside of work. Household responsibilities remain stable and relatively minimal.

5. Family Dissolution Stage: The structure of daily activity participation shifts strongly toward non-work and self-care routines. Participation in work and commuting drops sharply, while leisure, exercise, and socializing become the primary components of the day. Household duties and shopping are distributed across the morning and afternoon hours, and the overall daily rhythm is more relaxed—reflecting the increased time autonomy of older adults.

4. Time Pressure Identification and Markov Chain Behavioral Modeling

4.1 Identifying High Time-Pressure Periods

On weekdays, different family life cycle stages exhibit distinct patterns of time fragmentation. To identify high time-pressure periods across family types, this study uses fragmentation entropy as an indicator of activity-switching frequency and temporal discontinuity. A higher entropy value indicates more frequent activity transitions and greater behavioral dispersion within a given time interval, reflecting heightened tension in time management.

Following the approach of Shi et al. (2022), we adopt a fragmentation entropy threshold of 2.8 to define high time-pressure periods, based on the following rationale: (1) Across all life cycle stages, the value of 2.8 falls within the upper quartile of entropy distributions, indicating relatively intense time fragmentation; (2) As shown in earlier analyses, when entropy exceeds this threshold, behavioral patterns typically involve rapid transitions between work, household duties, and commuting—hallmarks of time fragmentation overload. Therefore, 2.8 is used as the dividing line between routine daily rhythms and high time-pressure conditions.

Figure 5 presents the fragmentation entropy curves for weekdays across different family life cycle stages, along with the identified high time-pressure periods.

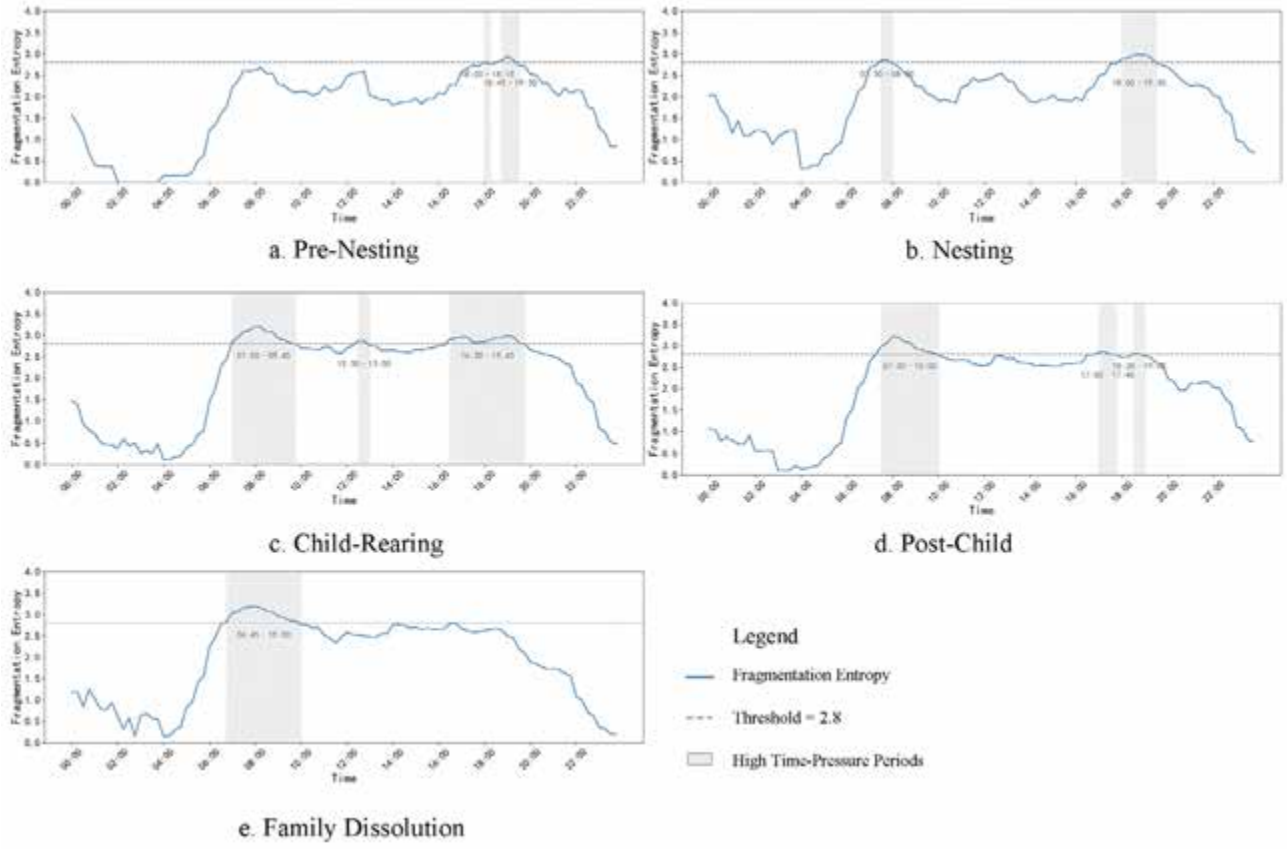

Figure 5. Intraday Variation of Time Fragmentation Entropy Across Life Cycle Stages

1. Pre-Nesting Stage: Entropy levels remain stable throughout the day, briefly exceeding the threshold only between 18:00 and 19:30. This suggests a generally manageable time rhythm with minimal scheduling stress.

2. Nesting Stage: Notable entropy spikes occur during two commuting peaks—7:30–8:00 and 18:00–19:30—highlighting time pressure arising from transitions between commuting, work, and emerging household responsibilities.

3. Child-Rearing Stage: Displays a clear "three-phase" structure of time pressure, with elevated entropy from 7:00–9:45 (morning commute and school drop-off), 12:30–13:00 (midday rest and domestic chores), and 16:30–19:45 (evening caregiving and household tasks). Entropy remains high for extended periods, marking this as the most prolonged and intense stage of time pressure.

4. Post-Child Stage: While the early morning (7:30–10:00) and evening (17:00–19:00) still show noticeable increases in entropy, the overall fluctuation is more moderate, reflecting reduced caregiving burdens and a partial alleviation of time stress.

5. Family Dissolution Stage: Elevated entropy appears only during 6:45–10:00, after which the daily rhythm stabilizes. This reflects a typical post-retirement pattern—high autonomy with concentrated morning activity followed by a slower, more relaxed pace throughout the day.

4.2 Identifying High-Frequency Behavioral Transitions Using Markov Chains

To further uncover behavioral patterns during high time-pressure periods across different family life cycle stages, Markov transition matrices were constructed based on the previously identified high-fragmentation time windows. These matrices model the weekday activity transitions for each of the five life cycle stages under time pressure. The matrices capture the probability of shifting from one activity to another, while the bar charts above each matrix (Figure 6) display the inflow probability of each activity type.

Overall, the structure of activity transitions under time pressure varies significantly across life stages, reflecting two key dimensions: the functional concentration of behavioral pathways and the complexity of transitions.

1. Pre-Nesting Stage (Figure 6a): The transition structure is relatively simple, with work remaining the central activity during pressure periods. The dominant transition pathways include Work - Commuting, Commuting - Meals, and Meals - Leisure, indicating a focused routine with few competing demands.

2. Nesting Stage (Figure 6b): Work and household responsibilities coexist, forming a dual-core transition structure. In addition to the work-centered transitions, notable pathways include Household Duties - Meals (0.34) and Leisure - Household Duties (0.21), suggesting an emerging division of domestic labor between partners.

3. Child-Rearing Stage (Figure 6c): The transition matrix is highly complex and densely connected, reflecting a multi-centered, high-pressure behavioral landscape. Prominent pathways include Education - Meals (0.19), Household Duties - Meals (0.21), Shopping - Household Duties (0.19), and Medical Care - Household Duties (0.21). These transitions form a dual-loop structure of education and caregiving, indicating the need for frequent multitasking. Notably, the inflow probability for Sleep is relatively high, highlighting a strong demand for restorative activities among residents in this stage.

4. Post-Child Stage (Figure 6d): Behavioral transitions shift back toward work and leisure. While work-related pathways remain visible, they appear more compressed. Commuting remains a burden, though household responsibilities begin to ease. Leisure activity sees an increase in inflow probability, suggesting a growing emphasis on personal time.

5. Family Dissolution Stage (Figure 6e): The transition network becomes significantly simplified, centering on a loop between self-care, household duties, meals, and leisure. Core pathways include Medical Care - Leisure (0.21) and Leisure/Exercise - Household Duties (0.23), reflecting a rhythm of health maintenance and relaxed daily living. The inflow probability for work-related activities drops sharply, underscoring a non-productive, high-autonomy time-use structure typical of older adults.

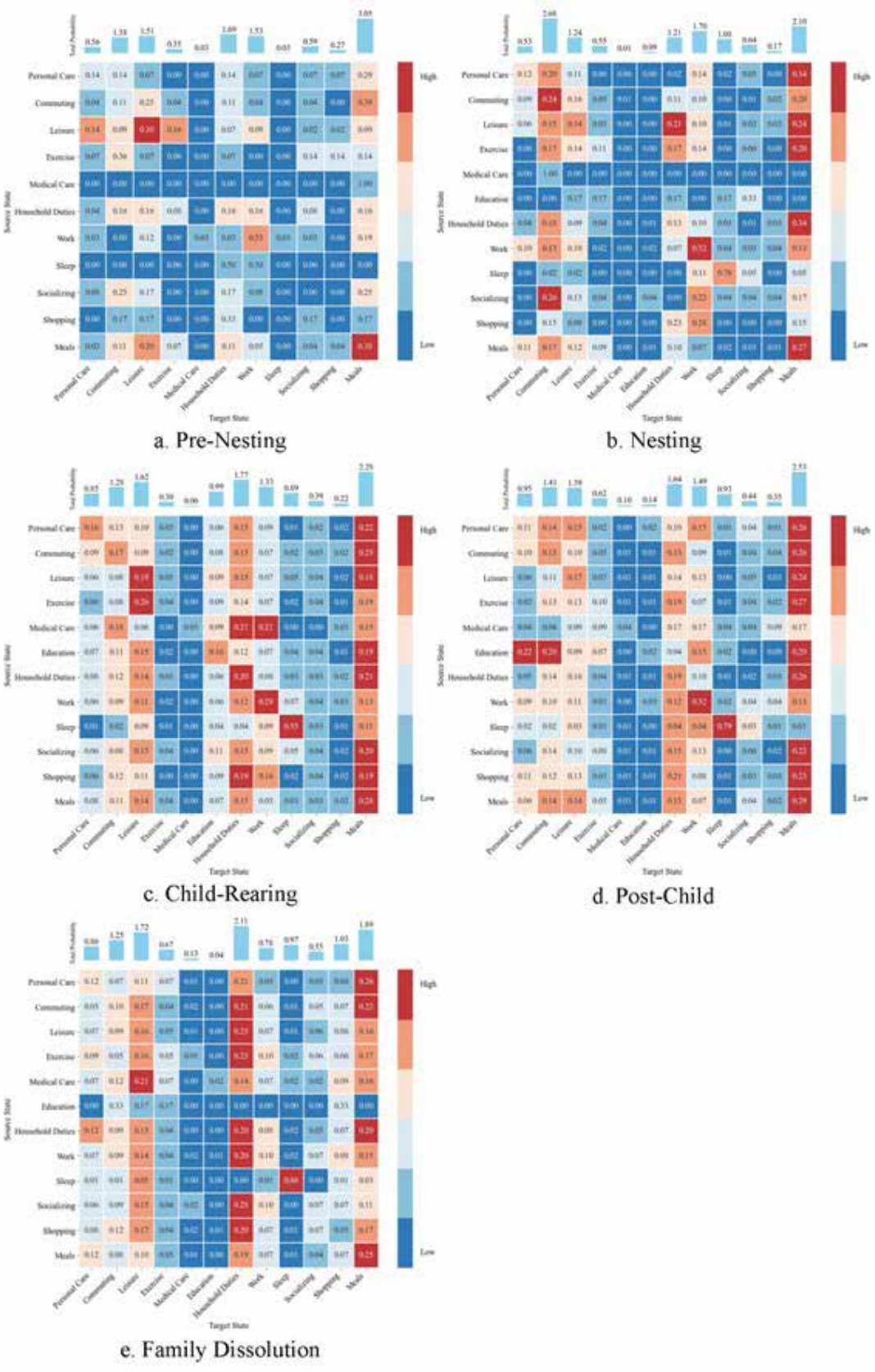

Figure 6. Markov Transition Matrices and Inflow Probabilities by Family Life Cycle Stage

5. Spatiotemporal Needs and Recommendations for Inclusive Urban Planning

5.1 Life Cycle–Oriented Spatiotemporal Matching Needs

With the integration of the family life cycle perspective, residents' time-use behaviors and spatial activity needs exhibit distinct stage-specific differences. Drawing on the earlier identification of high time-pressure periods and Markov-based behavioral transitions, we can pinpoint the unique time constraints, high-frequency activity pathways, and spatial stress points at each life cycle stage (Table 3).

Traditional urban planning—centered around a binary "residence–work" model—struggles to accommodate the complex, multi-role, multi-task, and multi-node behavioral patterns that emerge within family structures. This calls for a fundamental shift toward a spatiotemporal supply–demand framework that balances employment, caregiving, leisure, and aging needs. From the perspective of the family life cycle, spatial resources must be more flexibly adapted at the neighborhood scale. This provides a foundation for developing inclusive urban planning strategies that are responsive to the evolving demands of residents across different stages of life.

Table 3. Time-Pressure and Spatiotemporal Stress Points Across Family Life Cycle Stages

Family Life Cycle Stage	Time-Pressure Periods	High-Frequency Behavioral Pathways	Key Spatial Mismatches
Pre-Nesting	18:00-19:30	Work – Commuting – Meals – Leisure	Urban spatial design remains poorly aligned with the post-work evening routines of single young adults, with a lack of integrated online–offline options for nighttime dining and leisure.
Nesting	07:30-8:00 18:00-19:30	Commuting – Work Work – Household Duties Household Duties – Meals	There is limited last-mile connectivity between residential areas and public transit stations. Morning peak commuting is burdensome, and community-based convenience services need to be strengthened to help absorb household responsibilities.
Child-Rearing	07:00-9:45 12:30-13:00 16:30-19:45	Commuting – Work Work – Household Duties Education – Meals Household Duties – Meals Shopping–Household Duties	Spatial connectivity between education, dining, and shopping facilities is weak, creating overlap between commuting and caregiving demands. Community-level infrastructure for temporary childcare, midday rest, convenient pick-up/drop-off, and last-mile delivery requires optimization.
Post-Child	07:30-10:00 17:00-19:00	Work – Commuting – Meals Household Duties – Leisure	Commuting pressure remains significant, and there is a lack of diverse leisure spaces near residential areas tailored to the needs of middle-aged adults.
Family Dissolution	6:45-10:00	Household Duties – Meals Leisure – Household Duties Errands – Household Duties Medical Care – Leisure	Age-friendly upgrades are urgently needed in residential communities to support older adults' morning access to food and shopping. Additional public spaces for senior socialization, fitness, and wellness activities are also needed.

5.2 Recommendations for Inclusive Urban Planning

To address the spatial needs of different family life cycle groups during high time-pressure periods, urban planning and community renewal efforts should adopt more inclusive and differentiated service strategies:

1. Pre-Nesting Stage: Encourage the development of the nighttime economy in employment hubs and central commercial districts by supporting extended hours for dining and entertainment venues. Introduce digitally integrated leisure spaces—such as live-streamed night markets and immersive social platforms—to meet the post-work needs of single young adults for dining, entertainment, and social interaction.

2. Nesting Stage: Provide shared mobility services and last-mile connection infrastructure between residential areas and public transit stations, and improve multimodal commuting systems. Within neighborhoods, incorporate convenient service modules such as domestic help, community kitchens, and centralized laundry facilities to help ease the burden of household responsibilities.

3. Child-Rearing Stage: In response to the overlapping spatial demands of commuting, school drop-off, employment, and caregiving, establish neighborhood-level family service centers. These should integrate midday childcare stations, after-school care facilities, community kitchens, and parent–child activity spaces. Additionally, expand last-mile delivery access points for online shopping to reduce time pressure and caregiving costs.

4. Post-Child Stage: Encourage communities and business parks to provide flexible leisure spaces, such as social cafés and hobby workshops, to help alleviate the mental fatigue associated with balancing career and evolving family roles among middle-aged adults.

5. Family Dissolution Stage: Promote comprehensive age-friendly upgrades to communities, including the addition of accessible, pleasant small-scale shopping venues and senior meal stations. Develop senior-friendly greenways for exercise, social spaces, and smart assistive infrastructure to support physical activity and social participation among older adults.

6. Conclusion and Future Directions

This study, grounded in a family life cycle perspective, draws on the 2018 Shanghai Time Use Survey to examine how time-use patterns vary across different stages of the family life cycle. By identifying high time-pressure intervals and high-frequency behavioral transitions, the study proposes inclusive urban planning strategies that respond to stage-specific needs.

The findings reveal that individuals in the Pre-Nesting stage exhibit a work-oriented time structure characterized by high autonomy and strong engagement in nighttime leisure. The Nesting stage is defined by a dual-core structure balancing professional commitments and emerging household responsibilities. The Child-Rearing stage presents the most complex time structure, with family members engaging in frequent multitasking across work, caregiving, education, and domestic duties—making it the stage with the highest time pressure. In the Post-Child stage, time use shifts back toward a work-led structure with a gradual transition to leisure. Finally, the Family Dissolution stage is marked by a non-productive, highly autonomous daily rhythm.

Using fragmentation entropy and Markov chain modeling, the study identifies the peak pressure periods and dominant behavioral pathways for each life cycle stage, revealing the underlying time allocation mechanisms and corresponding spatial needs. Based on these insights, the research puts forward family life cycle–oriented recommendations for inclusive urban planning, including the creation of nighttime leisure environments for young adults, improved commuting buffers and caregiving infrastructure for families with children, and age-friendly spatial upgrades to support social participation among the elderly.

This study offers both a micro-level lens on residents' everyday spatiotemporal behaviors and practical guidance for building age-inclusive, caregiving-supportive cities. Nonetheless, certain limitations remain. The analysis relies primarily on cross-sectional data and does not yet incorporate multisource spatiotemporal information. Future research should integrate longitudinal time-use surveys with GPS-based spatial data to support higher-resolution analyses and more robust spatial intervention strategies.

References

Du, X., Zhen, F., & Jason, C. (2017). Influencing factors and spatial effects of residents' shopping behavior in Nanjing: A comparative study of four types of goods. *Geographical Research*, *36*, 957–971.

Glick, P. C. (1955). The life cycle of the family. *Marriage and Family Living*, *17*(1), 3–9. https://doi.org/10.2307/346771

Gui, J., & Chai, Y. (2014). Daily leisure patterns of suburban residents in metropolitan areas from a family life cycle perspective: A case study of Shangdi–Qinghe area in Beijing. *Areal Research and Development*, *33*, 30–35.

Han, S. Y., Liefbroer, A. C., & Elzinga, C. H. (2020). Mechanisms of family formation: An application of Hidden Markov Models to a life course process. *Advances in Life Course Research*, *43*, 100265. https://doi.org/10.1016/j.alcr.2019.03.001

Jiao, J., Wang, D., & Cheng, Y. (2023). Daily activity patterns and characteristics of time-poor populations in Shanghai. *Urban Planning*, *47*, 31–44.

Jiao, J., & Wang, D. (2021). The evolution, key topics, and future directions of urban time-use studies. *Urban Planning Forum*, 52–59. https://doi.org/10.16361/j.upf.202100006

Ma, Y., Tian, L., & Liu, L. (2023). Family life cycle and urban elderly tourism consumption: The moderating role of intergenerational interaction. *Tourism Science*, *37*, 1–18. https://doi.org/10.16323/j.cnki.lykx.2023.02.004

Mao, Y., & Li, J. (2020). Elderly daily life circles based on family life cycle theory: A case study of Xi'an. *Areal Research and Development*, *39*, 169–175.

Osman, M., & Ouf, M. (2021). A comprehensive review of time use surveys in modelling occupant presence and behavior: Data, methods, and applications. *Building and Environment*, *196*, 107785. https://doi.org/10.1016/j.buildenv.2021.107785

Pan, J. (2024). The impact of family life cycle evolution on residents' housing tenure choices (Master's thesis, Jiangxi Normal University). https://doi.org/10.27178/d.cnki.gjxsu.2023.000073

Perchoux, C., Brondeel, R., Klein, S., Klein, O., Thierry, B., Kestens, Y., Chaix, B., & Gerber, P. (2023). Does the built environment influence location- and trip-based sedentary behaviors? Evidence from a GPS-based activity space approach of neighborhood effects on older adults. *Environment International*, *180*, 108184. https://doi.org/10.1016/j.envint.2023.108184

Sen, Z., Ke, Z., Liu, X., Zhang, J., Yan, L., & Lian, Z. (2022). Characterisation of elderly daily travel behaviour in Tianjin using a space–time cube. *Environment and Planning B: Urban Analytics and City Science*, *49*(2), 603–618. https://doi.org/10.1177/23998083211019756

Shi, H., Su, R., Xiao, J., & Goulias, K. G. (2022). Spatiotemporal analysis of activity-travel fragmentation based on spatial clustering and sequence analysis. *Journal of Transport Geography*, *102*, 103382. https://doi.org/10.1016/j.jtrangeo.2022.103382

Song, L., Liu, H., Lyu, S., Niu, X., Hou, T., Ma, Y., & Lyu, Q. (2023). Exploring human behavior patterns and socio-demographic factors based on American Time Use Survey. *Concurrency and Computation: Practice and Experience*, *35*(5), e6878. https://doi.org/10.1002/cpe.6878

Sorokin, P. A., Zimmerman, C. C., & Galpin, C. J. (1931). *A systematic source book in rural sociology*. University of Minnesota Press.

Sturm, R., & Cohen, D. A. (2019). Free time and physical activity among Americans 15 years or older: Cross-sectional analysis of the American Time Use Survey. *Preventing Chronic Disease*, *16*, 190017. https://doi.org/10.5888/pcd16.190017

Wang, J., & Liu, P. (2024). Heterogeneity in household consumption from a family life cycle perspective. *Economic Forum*, 25–38.

Wang, S. (2024). The return and reconstruction of family functions in the new era: Reflections on the phenomenon of "full-time adult children." *Contemporary Youth Research*, 1–8.

Xia, C., Hu, Y., & Chen, J. (2023). Community time-activity trajectory modelling based on Markov chain simulation and Dirichlet regression. *Computers, Environment and Urban Systems*, *100*, 101933. https://doi.org/10.1016/j.compenvurbsys.2022.101933

Xiao, J., Lü, Y., Fu, M., Xu, M., & Cao, K. (2022). "Mixed-age renewal" strategies for aging urban neighborhoods based on intergenerational coordination within the family life cycle. *Urban Planning Forum*, 62–71. https://doi.org/10.16361/j.upf.202206009

Yang, G., Jin, W., Wang, Y., He, X., & Zhou, C. (2024). Differentiation and influencing factors of settlement intention among rural–urban migrants in the Pearl River Delta: A family life cycle perspective. *Geographical Research*, *43*, 411–428.

Zhao, H. (2023). The impact of working hours on urban employees' life satisfaction (Master's thesis, Inner Mongolia University). https://doi.org/10.27224/d.cnki.gnmdu.2022.000448