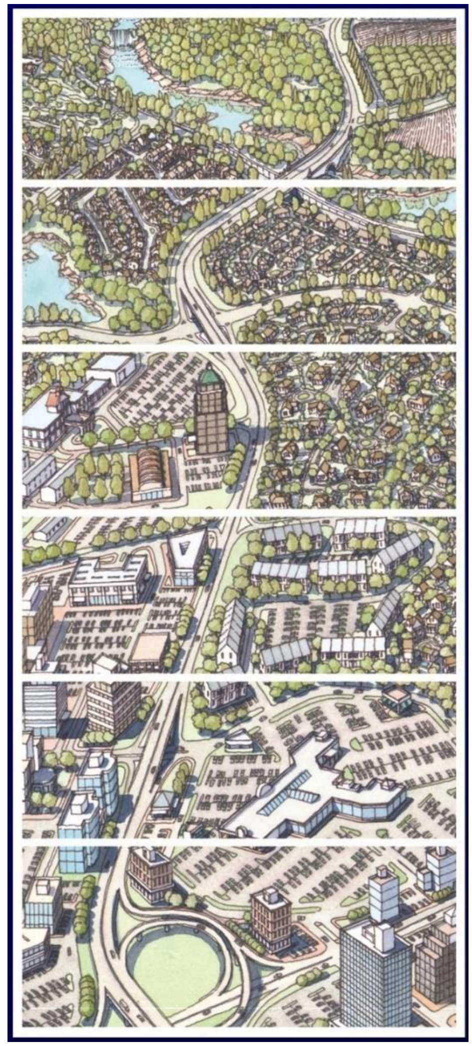
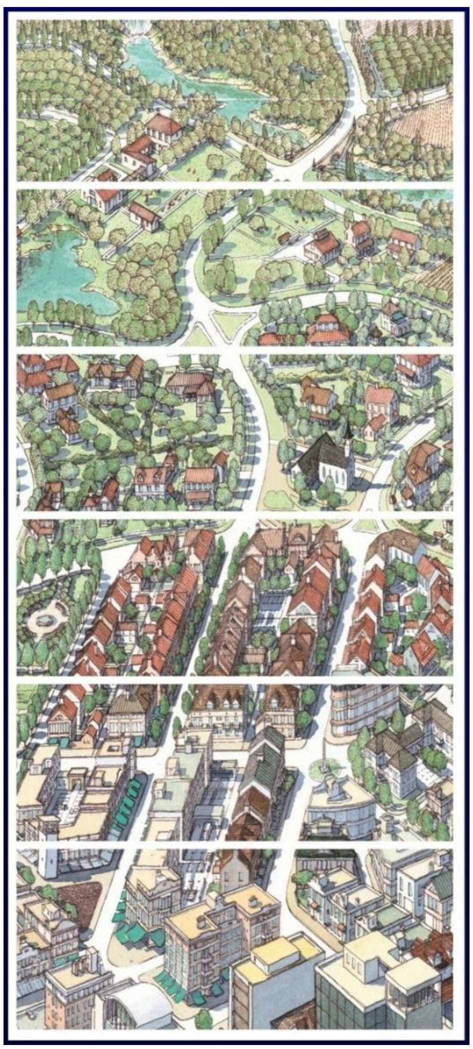
PURPOSE of PECAS



PECAS is a general theoretical framework and software platform for simulating the behaviour and evolution of urban and regional areas. This framework and software provide the concepts and associated computer programs used to develop a computer-based PECAS model that constitutes a comprehensive *digital twin* to a real-world city or region, a *digital twin* that accurately mimics the real-world and can be used to see how the real world would respond to changing stimuli over time. In particular, this *digital twin* is used to assess the impacts of potential planning actions like: building a new rail line, changing land development rules, subsidizing specific types of housing, or taxing energy use. It traces how these potential actions are expected to impact the evolution of real-world conditions into the future, using an inter-connected and holistic representation that can incorporate almost any elements of concern, including: sprawl, housing affordability, energy use, GHG emissions, transportation congestion, economic growth, business opportunities, and the distributions of these across locations and social groups. This *digital twin* provides planners, engineers, economists and decision-makers with the ability to test ideas and develop multi-faceted plans that more effectively and efficiently shape their city or region as desired. It also informs the discussions at the heart of decision-making where conflicting objectives must be balanced given limited resources.



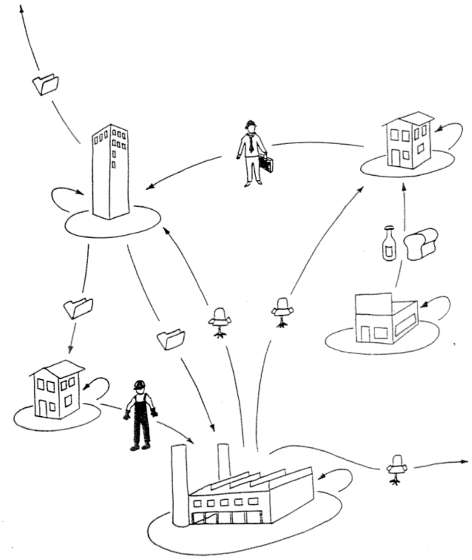
Source: from http://blogs.providencejournal.com/ri-talks/architecture-here-there/reburb2-16.jpg

The PECAS framework and software have been used and improved in more than 25 years of application around the World. The places with PECAS models are identified in red text on the map below. Some elements of PECAS and its application draw on and extend components tried and tested in the development and application of MEPLAN, an earlier land use transport modelling system. Identified in the blue text on the map are places that have MEPLAN models where these components were tried and tested with the involvement of some of the later PECAS developers – that reasonably can be viewed as precursor applications of some components of PECAS.

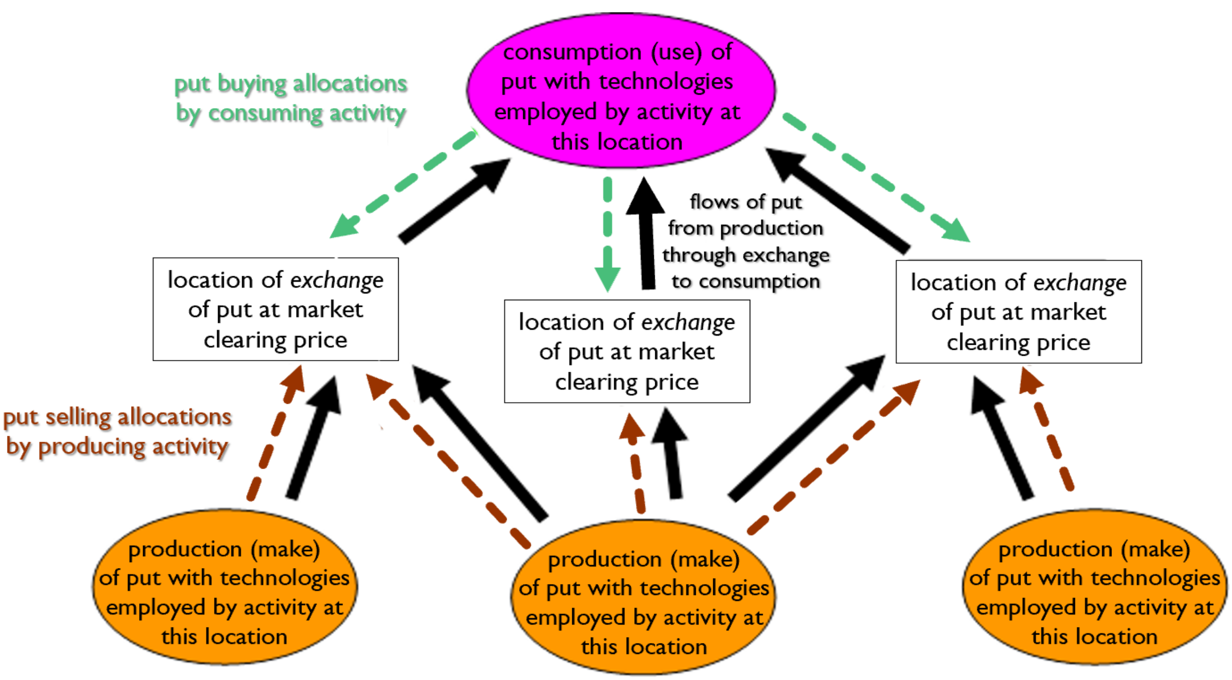
The name "PECAS" stands for Production Exchange Consumption Allocation System. It means "freckles" in Spanish. It is also the Latin basis for the word "peccadillo", which means little sin or small error and is indeed what is sought when endeavouring to model the real world.

Source: https//istockphoto.com/

THEORY of PECAS



PECAS concerns the spatial economic system, which includes the flows of goods and services and most everything else from the sellers who make these things to the buyers who use them to make other things and in turn become sellers themselves. More precisely, *activities* (like households and businesses) select *locations* (like homes and factories) where they employ *technologies* (like lifestyles and assembly lines) that use *inputs* (like food, fuel, metal, furniture, insurance services, hotel accommodation, white-collar labour, blue-collar labour, building space, etc) to make *outputs* (again, like food, fuel, metal, furniture, insurance services, hotel accommodation, white-collar labour, blue-collar labour, building space, etc). These *puts* (as both inputs and outputs) go from where they are made to where they are exchanged from seller to buyer for a price, and on to where they are used. The *put* prices at exchanges adjust to match supply and demand. *Activities* maintain *inventories* of *puts*, renting some and keeping others to use according to the *technologies* they employ. The flows of *puts* constitute the demand for person travel (like workers and shoppers) and transport (like food and equipment), and the nature of the *puts* together with the issues and costs in transporting them using the available transport system influence the decisions made by *activities*. The system evolves through time as the *activities* change in number and alter their location decisions in response to: evolving technologies, changes in *put* prices at exchanges and variations in transportation issues and costs.



Activities are the decision-making actors in PECAS. This includes categories of households, corporations, unincorporated businesses, non-profits, government, importers, exporters, and developers. Their behaviour – their motivations, sensitivities and trade-offs – are represented using random utility choice models.

The utility function for all types of *activities* other than developers considers location, technology and exchange alternatives. It scores the relative attractiveness of each option formed by combining a specific location, technology and set of exchanges for the relevant *puts*.

Utility for unit of activity a using technology t at location l

Additional utility associated with location l for activity a

Additional utility associated with technology option t for activity a

Quantity of put p produced or consumed under technology option t for activity a

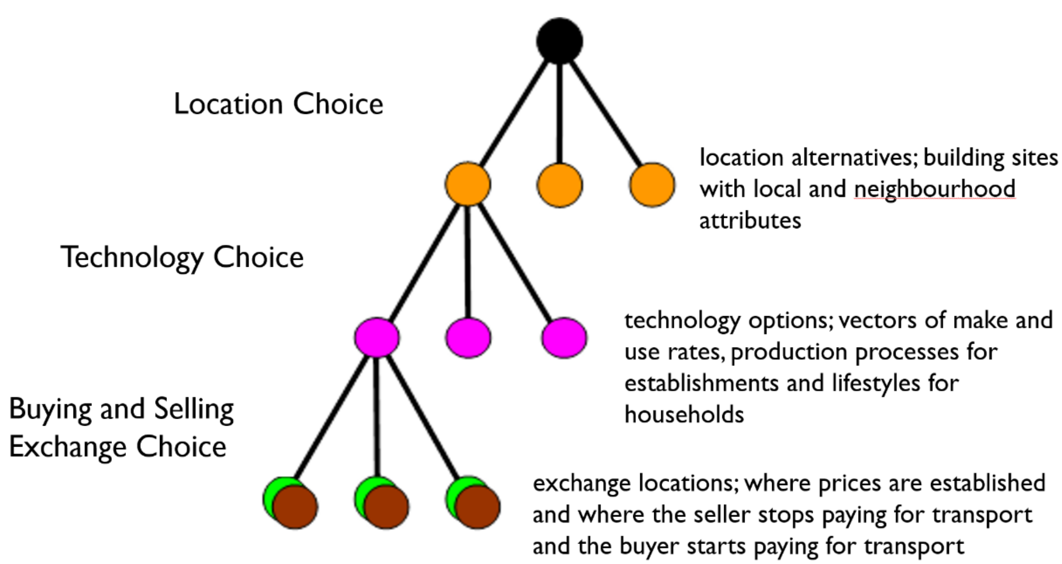
Utility of exchanging and shipping one unit of put p between l and e

$$U^L_{a,l,t,p,e_1 e_2 \ldots e_n} = AV^L_{a,l} + \varepsilon^L_{a,l} + AV^T_{a,l,t} + \varepsilon_{a,l,t} + \sum_{p \in 1 \cdots P_t} \left|\tau_{p,t,a}\right| s_{p,a}\left(V^E_{p,l,e} + \varepsilon_{p,l,e}\right)$$

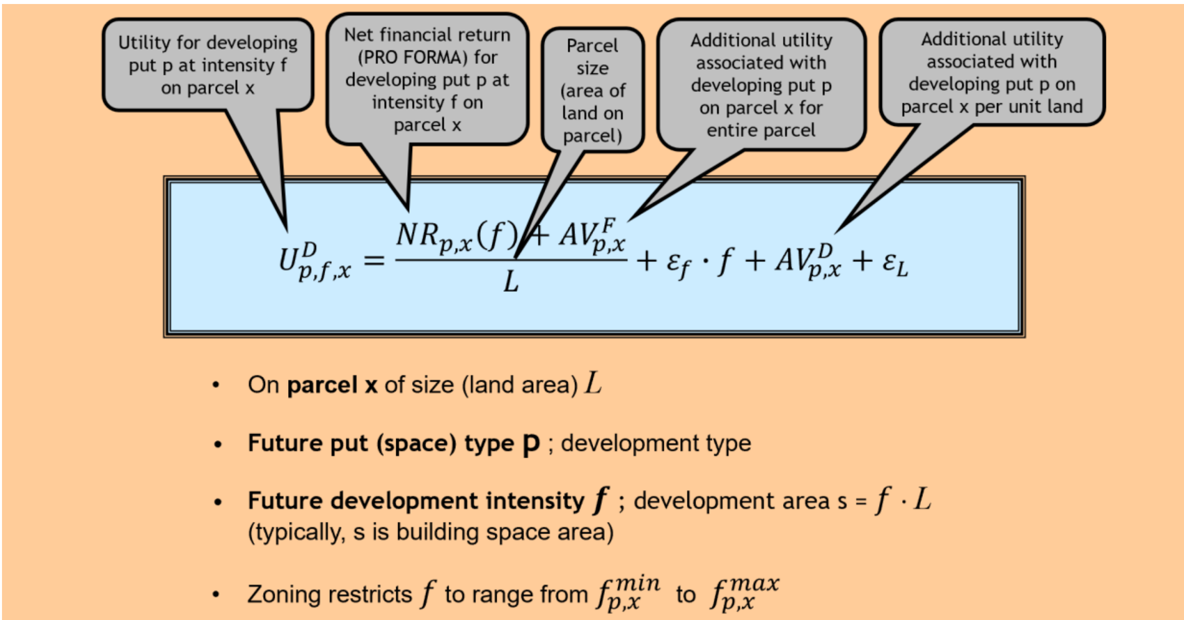
- **Location** l ; location of activity (residence or business establishment)
- **Technology option or lifestyle** $\boldsymbol{t}$; described by

  a set of technical coefficients $\tau_{p,t,a}$ for the set of puts P_t for technology t for activity a that expresses how much of each put p ∊ P_t is produced (or consumed, if $\tau_{p,t,a}$ negative) per unit of activity *a*
- **Exchange location** e ; for each put exchanged

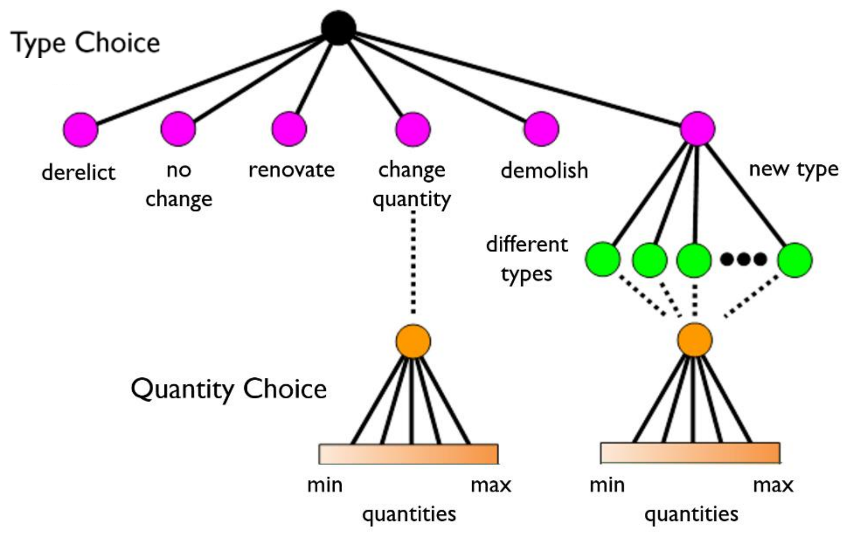
Drawing on random utility theory, and making reasonable assumptions about the specific mathematical forms for the distributions of the random error terms ε in the function above, the result is a three-level nested logit allocation model as follows:



The utility function for developers, the *activities* that construct non-transportable *puts*, concerns type and quantity alternatives. It scores the relative attractiveness of each option formed by combining a type (including action and building category) and a quantity of space where relevant.



Again, drawing on random utility theory, and making reasonable assumptions about the specific mathematical forms for the distributions of the random error terms ε in the function above, the result is a discrete-continuous two-level nested logit allocation model as follows:



In its simulation, the model considers each parcel in each time step, selecting whether existing buildings (if any) are left to go derelict, maintained, renovated, or demolished and whether there is new construction of the same or a different type and at what intensity. Developer behaviour responds to prices by building type and the costs of construction and maintenance. Land use regulations at the parcel level constrain what is permitted.

Puts . . . .





include everything produced, exchanged and consumed in PECAS, anything that is included in the inputs or outputs of a given technology. This includes categories of raw materials, commodities, energy, goods and services, building space, labour, waste and even other emission outputs of concern in a given context such as GHGs or noise. Key attributes of *puts* in PECAS are their unit prices at exchanges and the factors influencing their transportability and associated transport unit costs, including whether they are fully consumed when used (like fuel) or not (like equipment); necessarily used when made (like hotel accommodation) or possibly stockpiled (like fuel); exchanged where made (like metal) or where used (like labour); transported in full each day (like labour) or in portions (like metal); or even non-transportable and by necessity exchanged and used where made (like building space and other infrastructure).

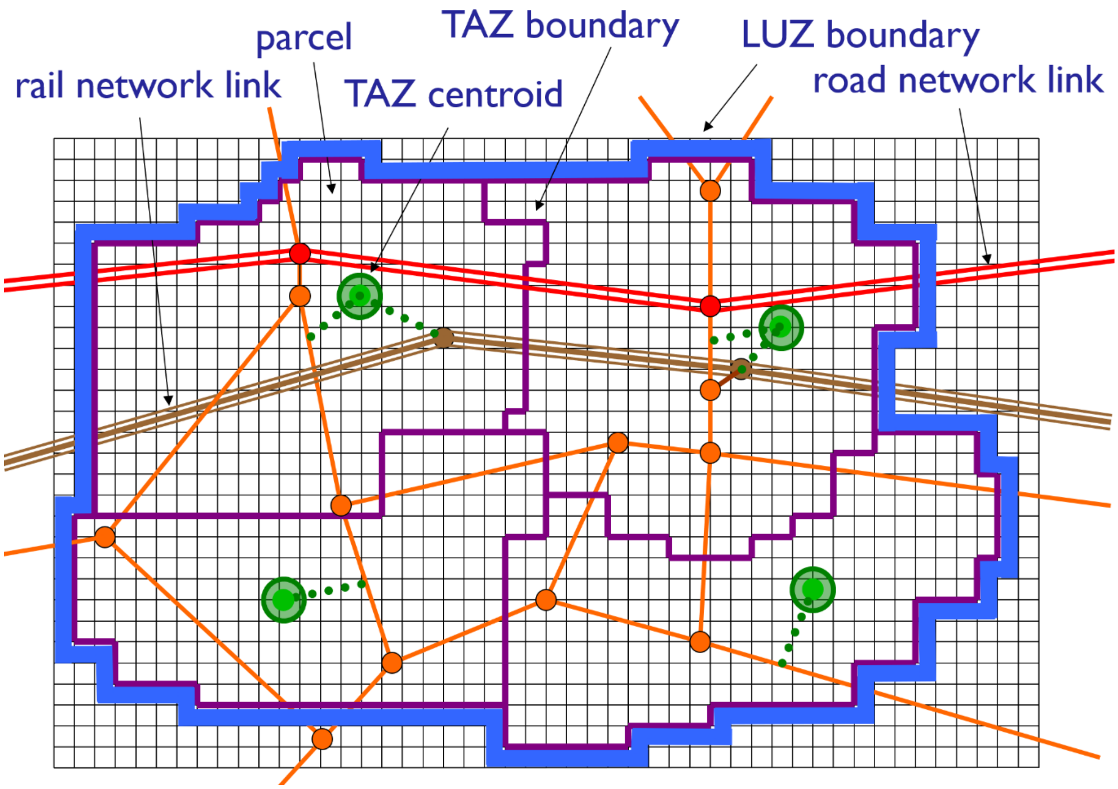







Source for all images on page: https://stock.adobe.com/

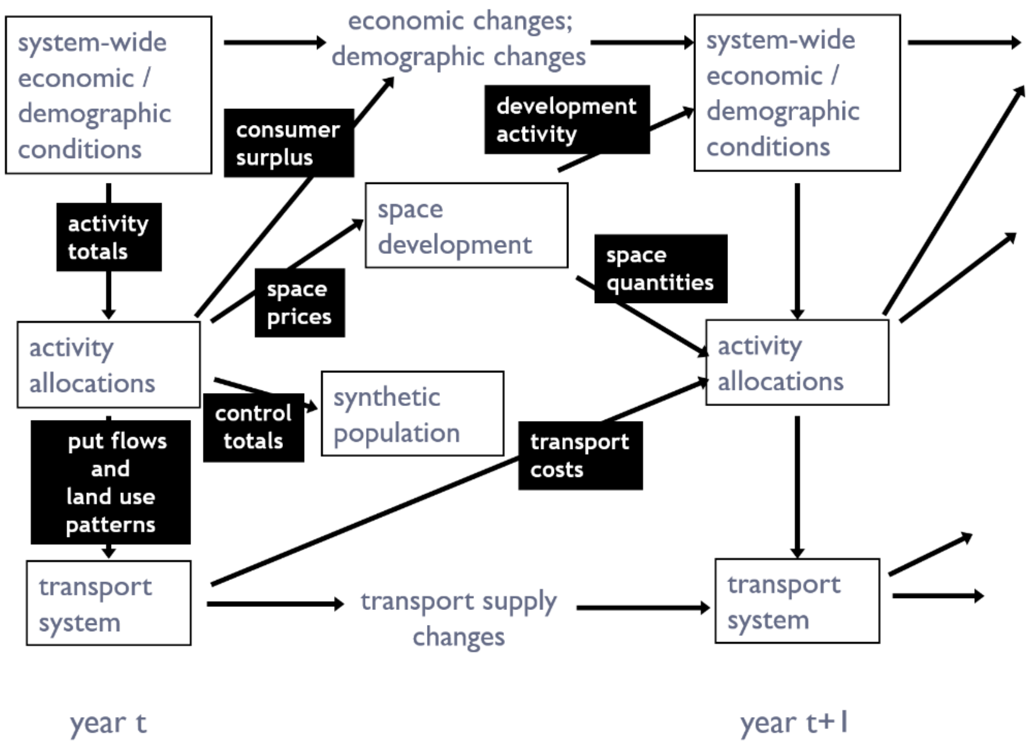
Space is represented in PECAS using *zones* and *networks*. A two-level hierarchical system of zones is applied. The land use zones, or LUZ, used in the consideration of activity location and technology selection are further sub-divided into smaller transportation analysis zones, or TAZ, that provide a greater resolution more suitable for consideration of important local-level travel conditions.



Zones, both the LUZ and TAZ, contain parcels that are the precise locations where non-transportable *puts* such as buildings and other infrastructure can be built. The impacts of changes in the rules regarding what can be built are considered with the model by making these changes for the parcels in the model and viewing how the behaviour of the model changes as a result – what new development patterns emerge and who uses them to what benefit. Changes in the built form, buildings and infrastructure can also be coded directly onto the parcels as a representation of direct development policy to view how the model responds.

Networks connect the zones and allow the transportable *puts* to flow between them. They provide the model with its simulation of the real-world networks, and the impacts of changes to the transportation system are analyzed by adjusting the model networks and viewing how the behaviour of the model changes as a result – how travel patterns change, what changes in the evolution of the built form, to what extent other elements of the system are impacted, and who benefits.

Evolution of the system over time is simulated in steps from one point in time to the next (like from year t to year t+1).

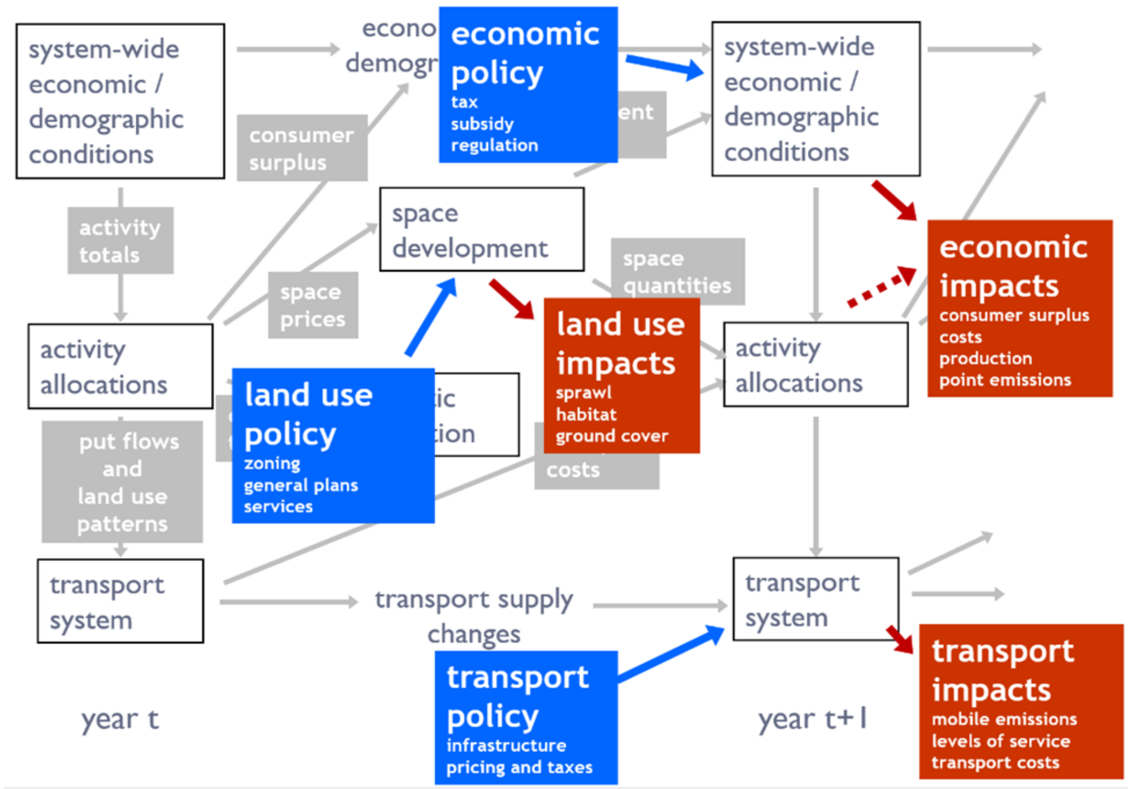


Subsequent points are considered in turn until the full planning period is covered. This has ranged from 10 to 75 years into the future in practical applications.

At each point in time, model-wide activity totals are established using aggregate econometric models, demographic models, extrapolations of trends and received forecasts depending on context. These activity totals are allocated to the model zones and technologies and the corresponding *puts* are allocated to exchanges using the random utility choice models, this done in iterations with the *put* prices at exchanges adjusted until demand and supply match. This constitutes a unique short-run equilibrium solution for the point in time. A disaggregate synthetic population consistent with these allocations is developed for use in fine-level analysis of impacts and potential further micro-simulation. The flows of *puts* are translated into transport demands that are loaded to the available networks and the resulting congested times and costs are used in the activity allocations performed in the consideration of the next point in time. The changes in building space and potentially other infrastructure in the model zones over the duration from one point in time to the next are established using the random utility choice models for developers with the prices for building space (actually rents) determined in the prior activity allocation.

This configuration of steps from one point in time to the next with short-run equilibrium and lags for construction and for reactions to transportation conditions provides an explicit representation of the inertia in the system consistent with the real world. The representation can be further enforced by limiting the rate of turn-over in the built form and calibrated more finely using lag terms in the activity location utility functions as part of model development.

Assessments of the impacts of potential planning actions are made by comparing simulations of the system with and without the action included. This includes system interventions (like new roads or rail lines, altered zoning regulations on development, subsidies for low-cost housing, etc) as well as the introduction and/or support of new technologies (like reduced emission manufacturing, increased robotics, smart electrical use, etc).



Planning and policy actions, whether economic, land use, technological and/or transport, are input in the appropriate system modules (shown in blue) and the impacts arising from the interactions among the components and over time are output (shown in red). This facilitates a holistic assessment of the impacts in all components arising from the planning actions taken in the same or other components. Consistent with random utility theory, changes in the choice utilities for *activities* are equal to changes in consumer surplus and as such provide numerical (and potentially money equivalent) measures of the benefits these *activities* are realizing as the system evolves. This provides a basis for robust benefit cost analysis that includes equity (or distributional) as well as efficiency impacts.

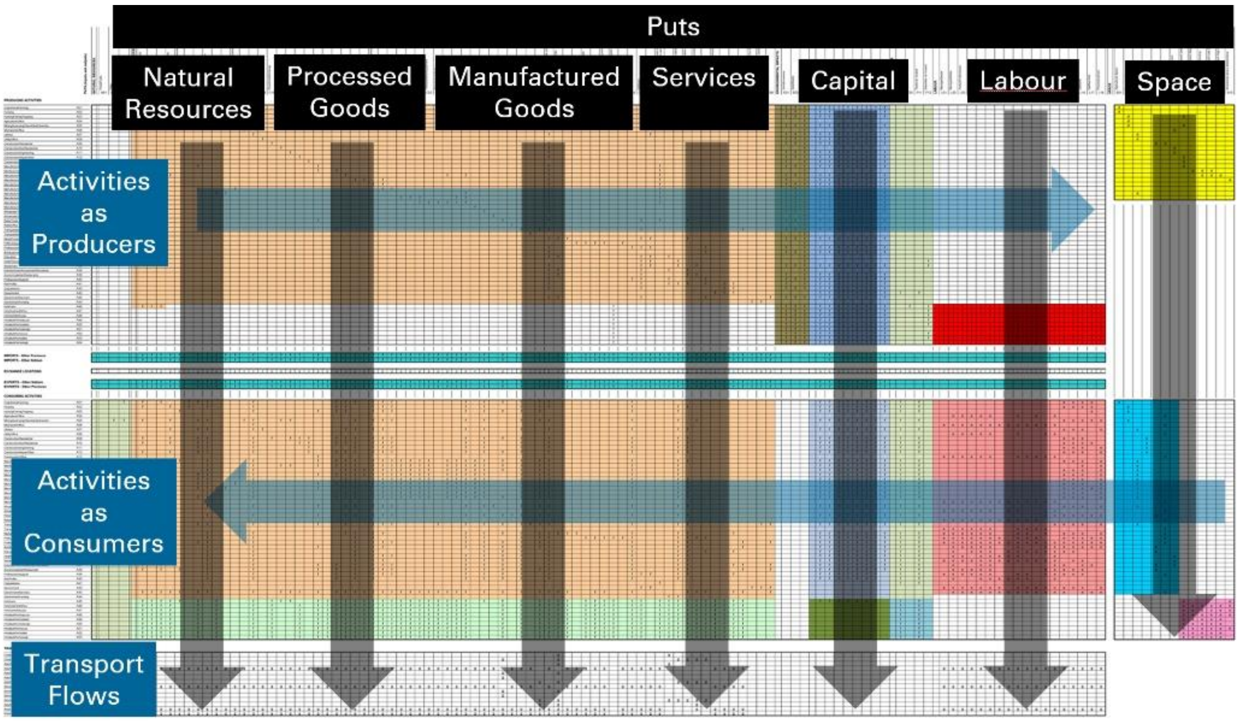
APPLICATION of PECAS

The PECAS Framework provides a structure for interpreting the real world and a basis for defining the behaviour and interactions to be represented in the *digital twin* model to be developed in a given instance. It also forms a repository for the modelling techniques and other know-how that have been obtained over many person-years of experience, making it available for subsequent application.

The PECAS Software holds the computer routines, accepts the input files and produces the outputs for realizing a given PECAS model. It runs the simulation that forms the *digital twin* in a given instance.

The PECAS model for a certain city or region has specific categories of *activities*, *puts*, and *technologies* with calibrated parameters for the equations simulating their behaviour and interactions. Much of the effort in the design and development of the given PECAS model involves defining these categories and establishing these calibrated parameters – along with gathering and processing the data and developing the parcel records and transport networks. Establishing a suitably accurate, rich and comprehensive *digital twin* requires substantial data collection and development. An “agile” approach is used: a model with a rough representation covering the entire system using a few broad categories is quickly implemented first, and then increasingly refined versions are developed in successive iterations. Each new release with its elements of improved representation provides better indications for a wider range of issues. Ideally, there are two teams of modellers working on two streams of activity: one on the iterations of model development and the other on application of the most recent releases in analysis work that supports real-world planning activity.

A formalized PECAS Design Diagram is used to depict the categories and interactions included in a given PECAS model.



Each activity category is a row as both producer (of *OUTputs*) and consumer (of *INputs*). Each *put* category is a column that flows from the row for its production down to the row for its consumption, through rows for imports that add and exports that subtract to the supply of *puts*, and then down to a row for its corresponding transport flow in the transport model. Letter codes at the intersection of rows and columns indicate the treatment, including the mathematical formulation, of the corresponding interaction. Standard colors are used to indicate where the treatment of specific components of the system are considered, which also implies the sorts of data that would inform the development of this portion of the model: red for the production of labour by households, yellow for the land and zoning permissions for development of building space, tan for industrial inputs and outputs, green for household consumption, pink for use of labour, blue for the financial markets, teal for use of non-residential buildings and purple for use of residential dwellings. This indicates the relative emphasis and the degree of resolution of the various components of the system, displaying how the specific model design provides more focus on issues of specific relevance in the context of the application – for example, including a greater number of more narrowly defined categories of dwelling type and tenure to support analysis of housing policy, or more categories of industrial *activities* and *technologies* to support consideration of GHG emissions.

Some examples of PECAS applications are presented below in brief two-page summaries. These indicate features of the model design and show the Design Diagram, describe the planning analysis and wider context of the work, and highlight some of the results obtained.

PROCUREMENT of PECAS and TECHNICAL SUPPORT

PECAS is the product of more than 25 years of work by a long-standing team of engineering and planning experts, working together in the consulting firm HBA Specto Incorporated based in Calgary in Canada. Some team members have up to 15 additional years of prior experience in modelling in consulting, government and academia. This group has developed the theoretical framework and software, extending these as more is learned through experience in application. Its team members are the source of the critical know-how in data collection and processing, modelling techniques, parameter estimation and model calibration that can ensure a successful model development. They also have extensive experience training the in-house staff of a client agency to perform future work in both model enhancement and application.

For more information about PECAS and how to apply it in your city or region, together with obtaining expert support and training in model design, development and application, contact: HBA Specto Incorporated at jea@hbaspecto.com and see the website at www.hbaspecto.com