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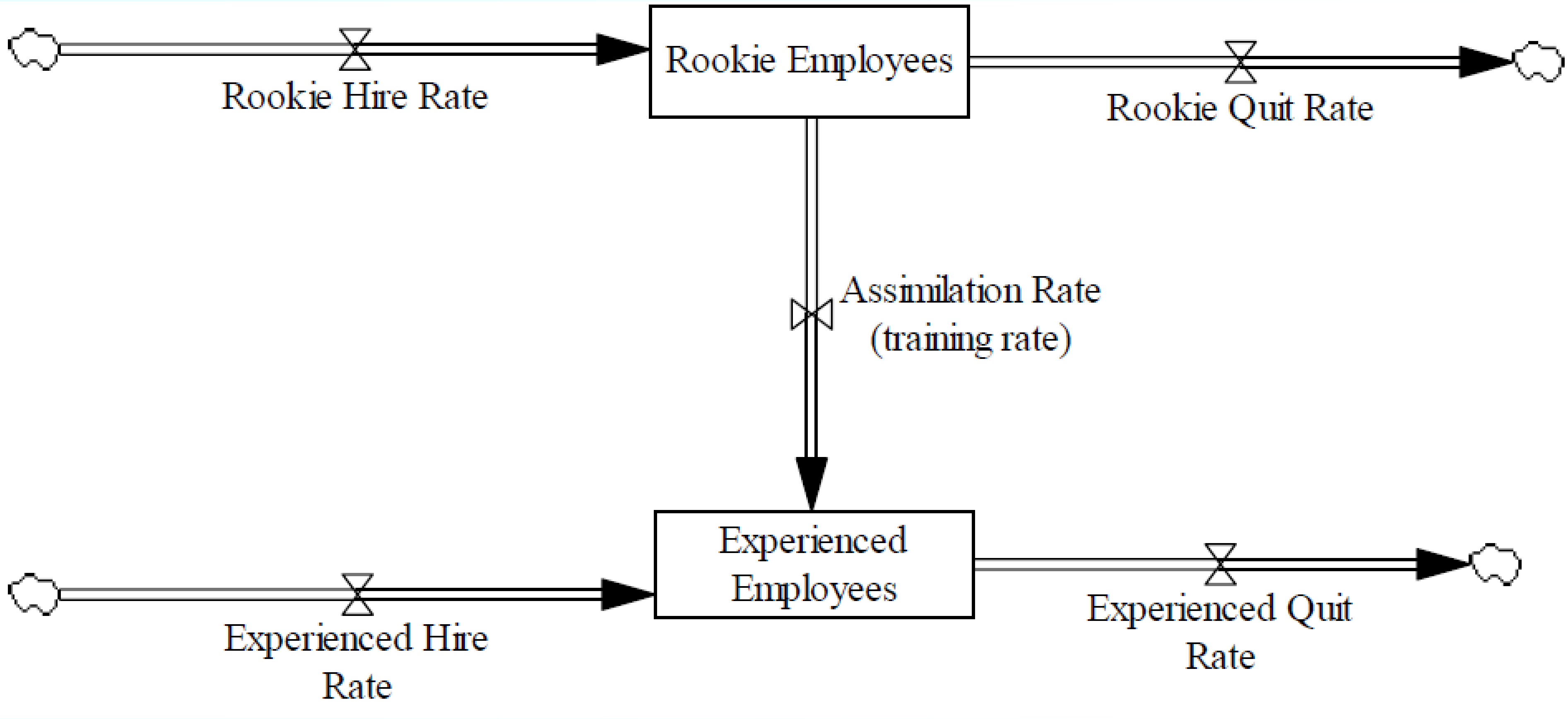
School of Science

Coflows and Aging Chains

Aging and development

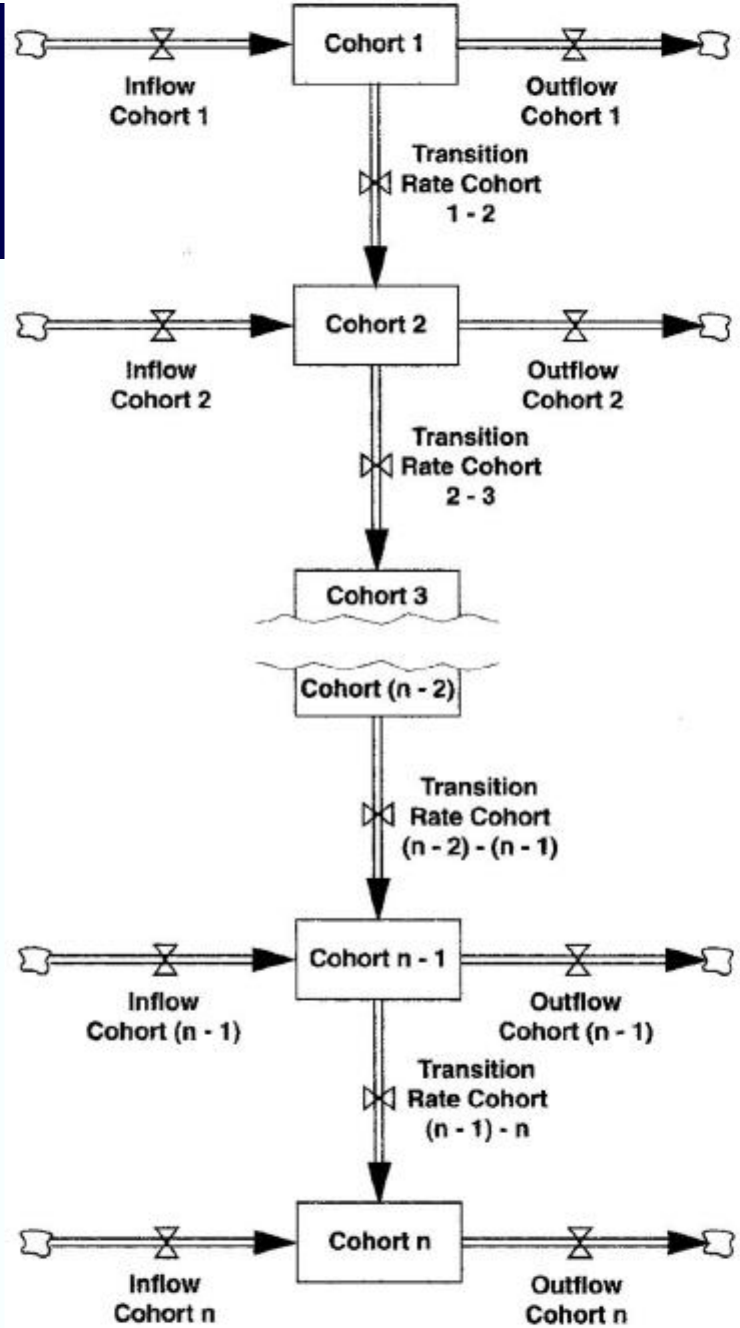
- All material flows entering the system as input normally also leave the system as respose
- However, material can change form, age and develop within the system
- The material leaving the system can be in different development phases
- Aging chains are used to model this
  - Examples:
  - Trained personnel in a company
  - Population demographics
  - Fault rate of machines as function of service interval
  - Divorce rate as function of marriage duration

Aging chain example: employee development

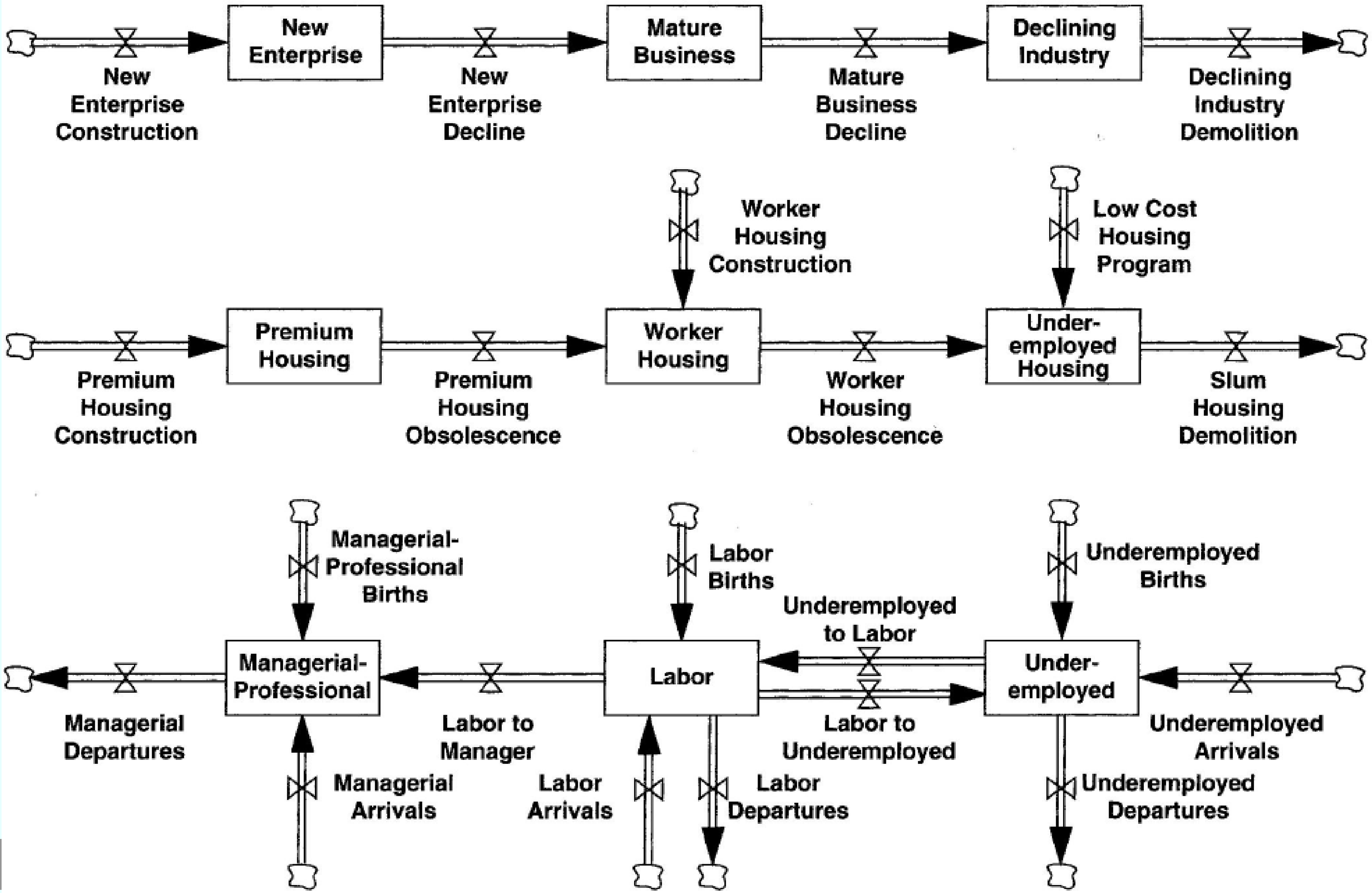


General aging chain structure

- Any number of *cohorts* (levels)
  - Any number of inflows ad outflows for each cohort
  - Material transits between cohorts according to transition rate
- Material level C(i) is integral of inflows - outflows
  - Typical transit rate $T(i, i + 1) = C(i)/ YPC(i)$
  - *YPC* = Years per cohort



Example: Urban dynamics (Forrester 1969)

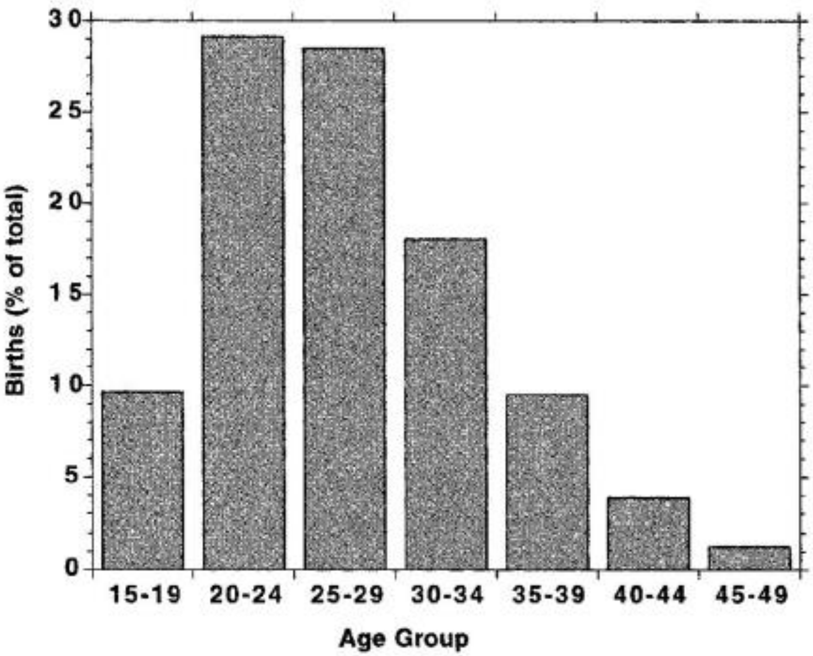


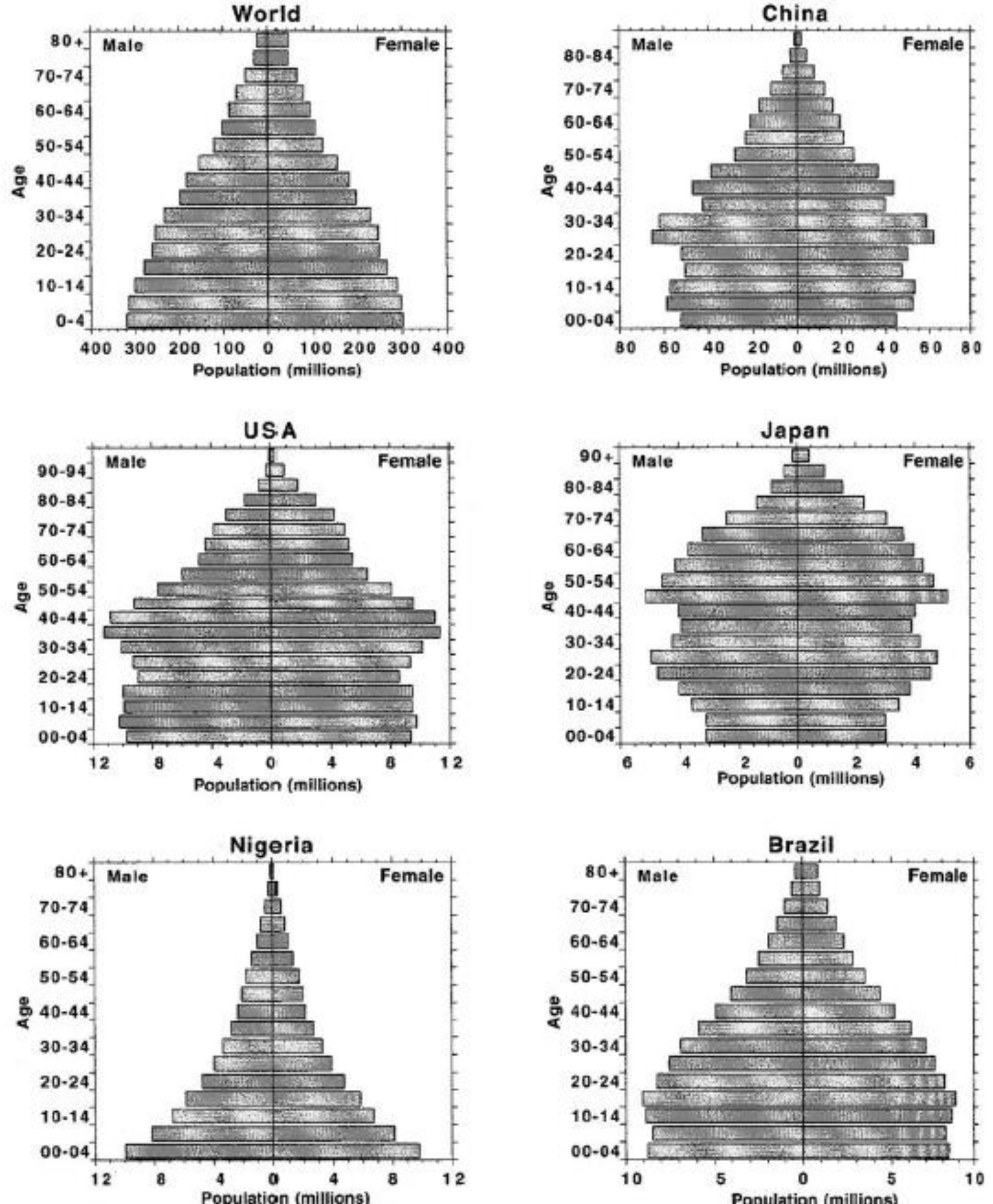
Example: Urban dynamics (Forrester 1969)

- Model is deliberately very simple
  - All possible flows are not included
  - Office buildings cannot be converted into residence
  - Houses cannot be renovated
- Conclusions by Forrester
  - "Depressed areas in cities arise from excess low-income housing rather than from a commonly presumed housing shortage"
  - Recommends "simultaneously reducing the aging housing in decaying cities and allocating land to income-earning opportunities"

Demographic models

Right:Very different population pyramids in different countries
Below: World average distribution of births by mothers' age





Demographic models

Population is divided into cohorts P_i according to age group

Flows

B = Birth rate

I_i = Net immigration

D_i = Death rate

M_i = Maturation rate

$$P_0 = \int (B + I_0 - D_0 - M_0)$$

$$P_1 = \int (M_0 + I_1 - D_1 - M_1)$$

$$\vdots$$

$$P_i = \int (M_{i-1} + I_i - D_i - M_i)$$

R_i = Exit rate

$S_{F,i}$ = Survival fraction

F_T = Fertility rate

S_s = Gender distribution

Y_{CF} = Last childbearing year

Y_{CI} = First childbearing year

w(a) = share of childbearers in P_a

$$B = S_s \left(\frac{F_T}{Y_{CF} - Y_{CI} + 1} \right) \sum_{a=Y_{CI}}^{Y_{CF}} w(a) P_F(a) \quad , \quad \sum_{a=Y_{CI}}^{Y_{CF}} w(a) = 1$$

$$M_i = R_{E,i} \cdot S_{F,i}$$

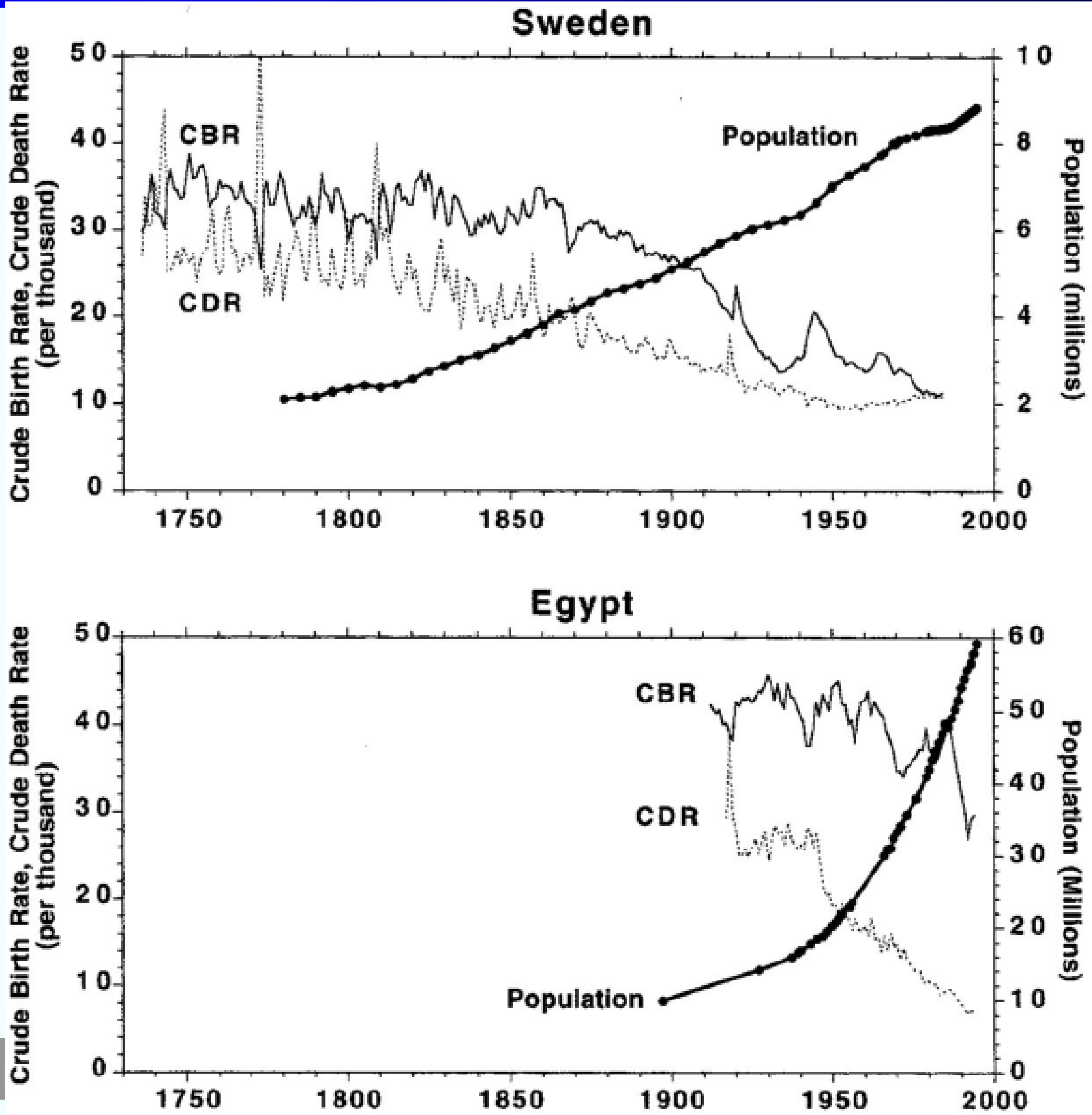
$$D_i = R_{E,i} \cdot (1 - S_{F,i})$$

$$R_{E,i}(t) = M_{i-1}(t - Y_c) + I_i(t - Y_c)$$

Population growth

Sweden vs Egypt
CBR = crude birth rate
CDR = crude death rate
(births or deaths per 1000 people per year)

- Population of Egypt doubled in 30 years
- Sweden doubled its population in 120 years



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World population

- World population has great intertia
- SD study by Meadows (1972):
  1. The carrying capacity of the earth will be exceeded within 100 years due to population growth. This will most likely lead to sudden and uncontrollable decline in population and industrial capacity
  2. It is possible to alter these growth trends and to establish a condition of ecological and economic stability that is sustainable far into the future
  3. The sooner the worlds people decide to do this, the greater will be their chance of success.

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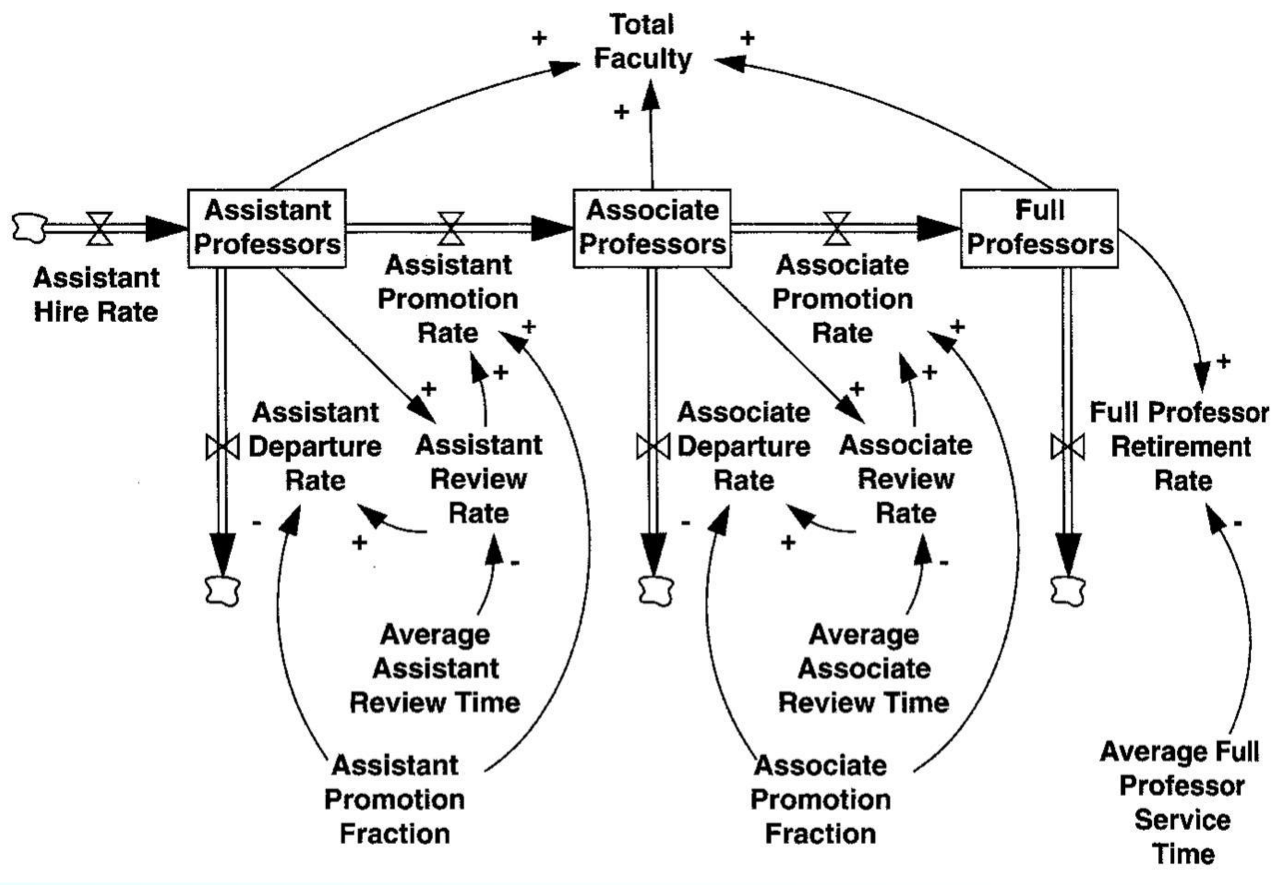
Growth and age structure of organizations

- Most organizations contain various *promotion chains*
  - Associate, senior associate, partner, director
- Growth rate has dramatic impact on the balance among the levels of the promotion chain
- When growth speed changes, also the ratio of junior vs senior employees changes
  - Managers and directors become over-represented when growth slows down
  - This is a great threat for successful, fast growing organizations

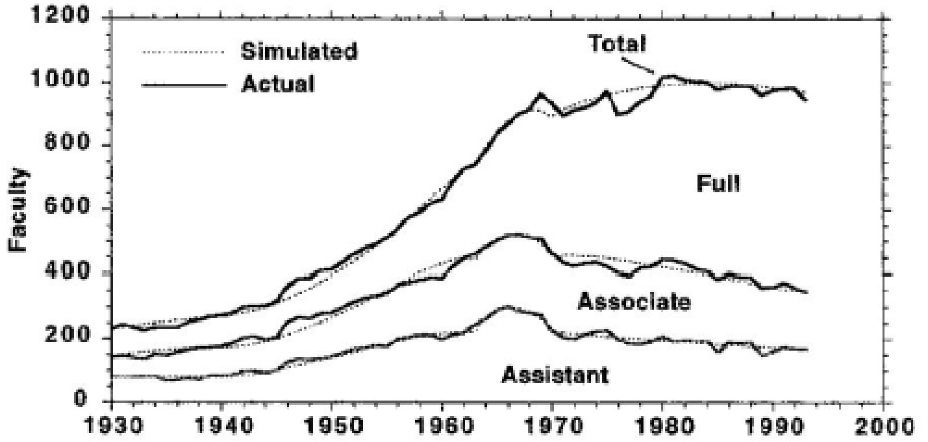
Example: Universities in USA

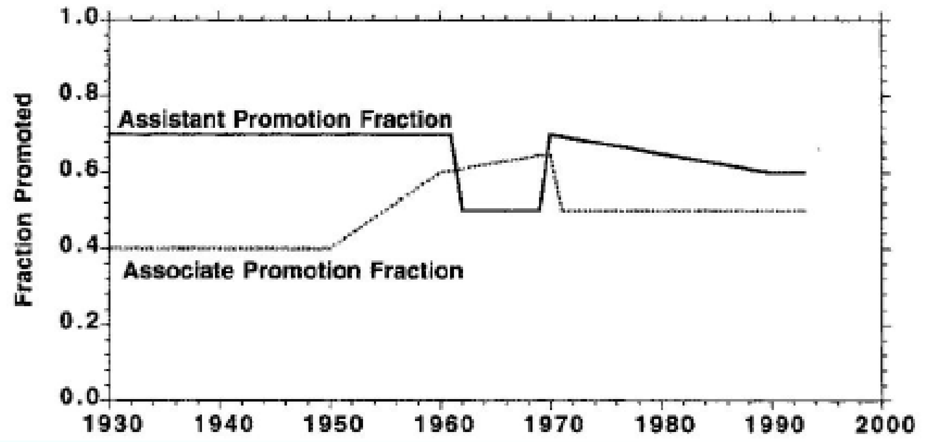
- Up-or-out promotion system = 3rd order delay system
- Almost all hirings on ass.prof level
- About 50% are promoted
- Average delays
  - 3 years ass.prof
  - 5 years assoc.prof
  - 35 years full prof
- Little's law ⇒
  - 21% ass.prof
  - 18% assoc.prof
  - 61% full prof

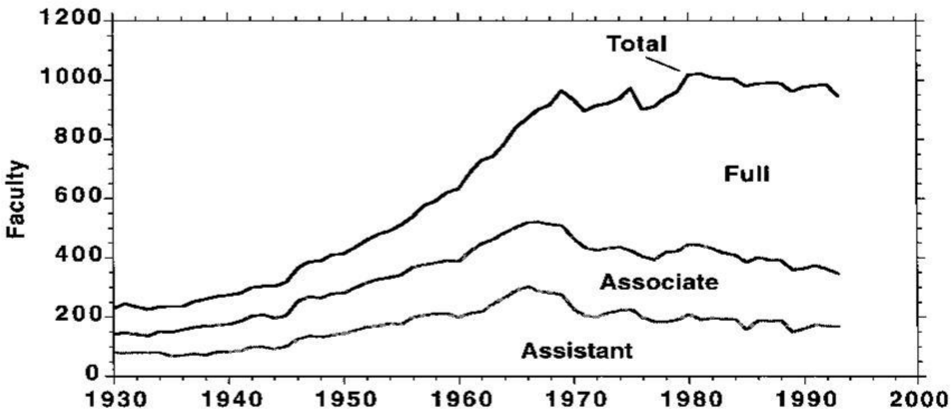


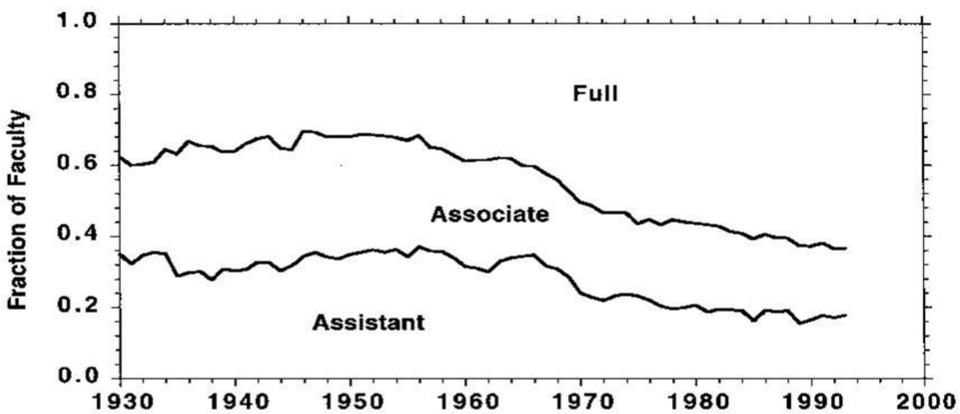
Example: MIT

Below: MIT faculty ranks
Right: Simulated



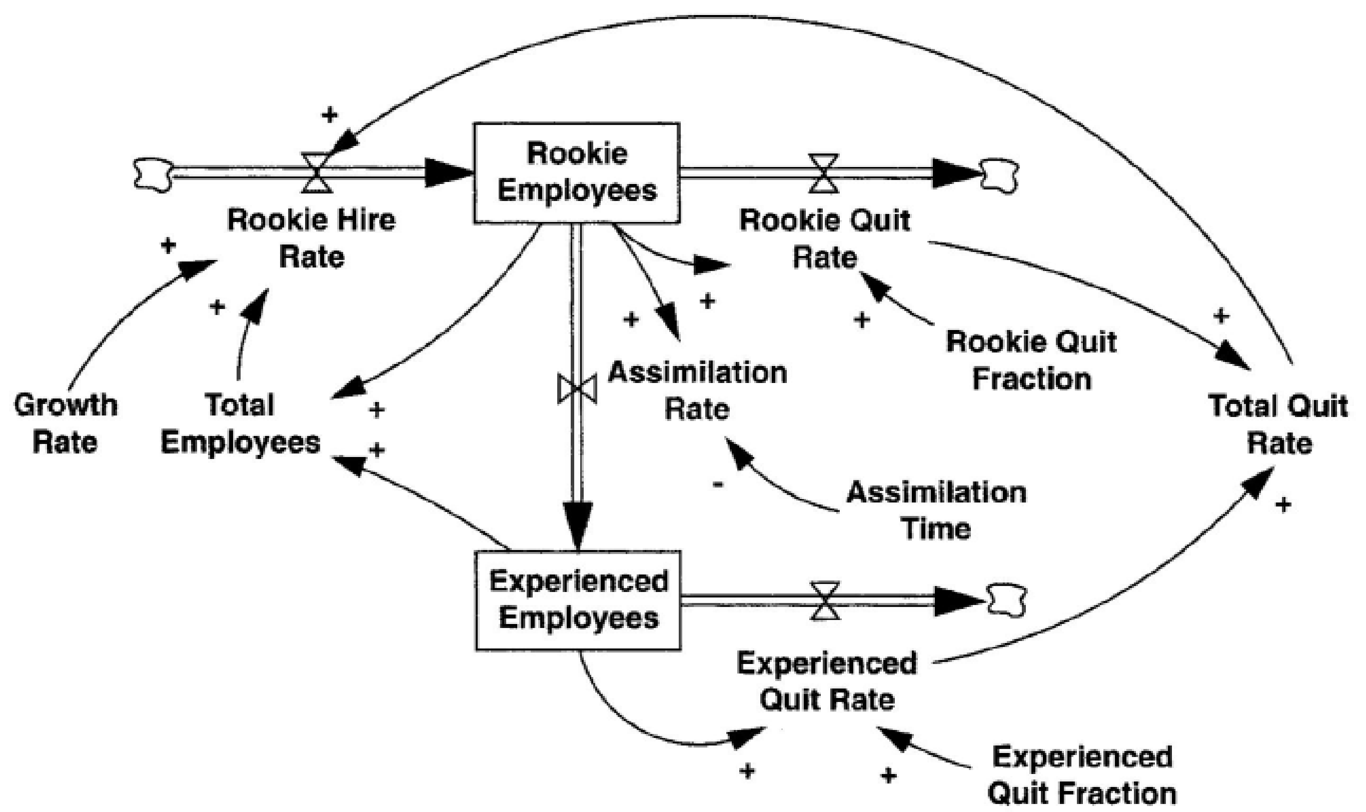




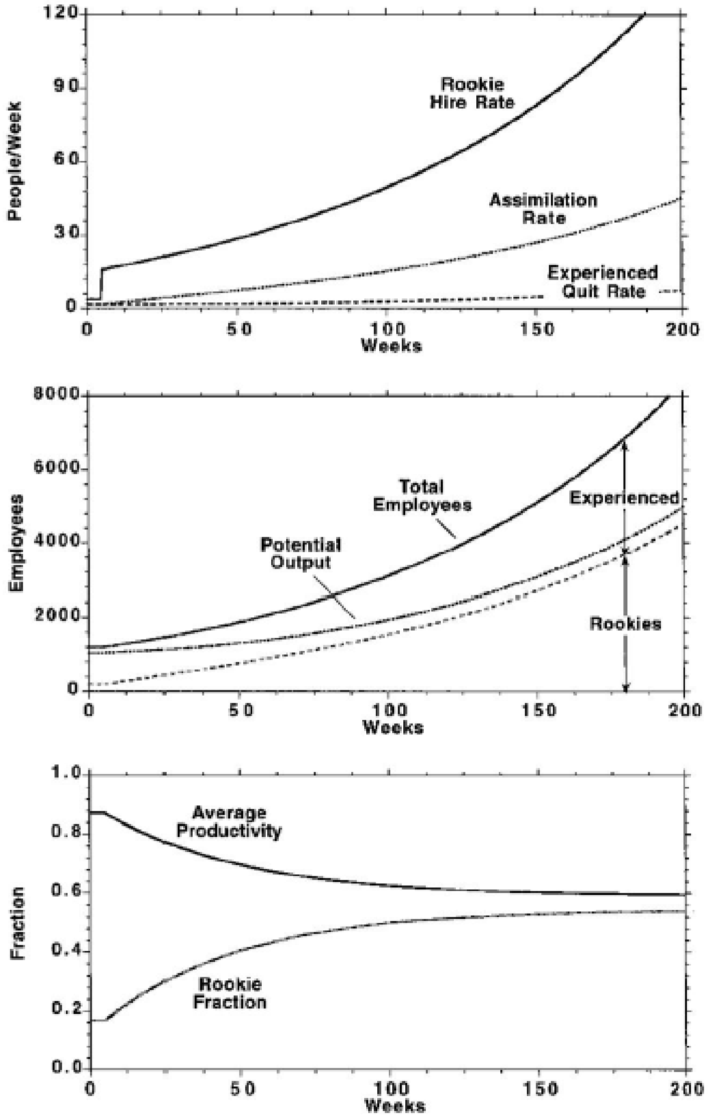


Promotion chains and the learning curve

- Two cohorts: Rookies and experienced employees
- Experienced are more efficient than rookies
- Company is growing exponentially

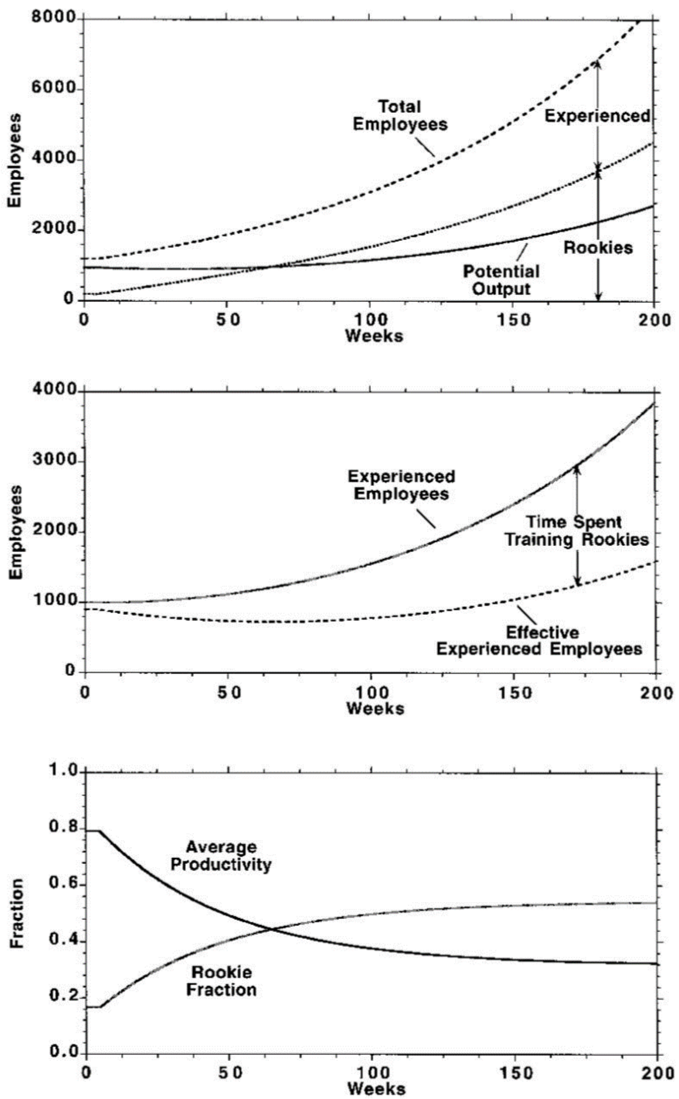


Response of two-level promotion chain to growth



Left: without mentoring

Right: mentoring by experienced employees required: Productivity drops significantly

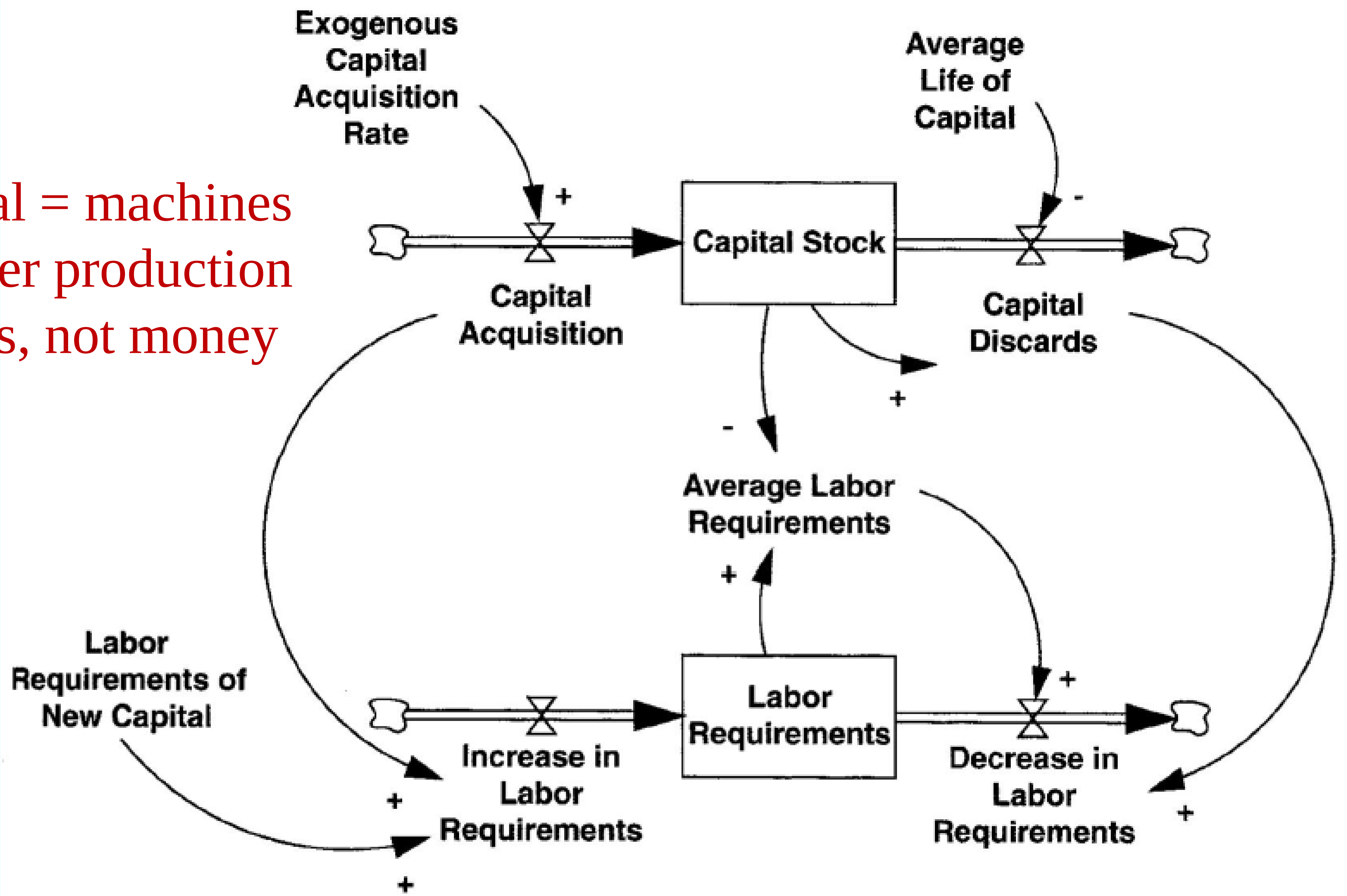


Coflows

- Often material flows have attributes that need to be tracked
  - Employee skills and experience
  - Efficiency of machines
- These attributes can be modelled by *coflows*
  - Attributes flow in parallel to the material flows
  - Coflows have the same structure as the material flow
- This is a programming trick, because the variables are only scalar values without structure

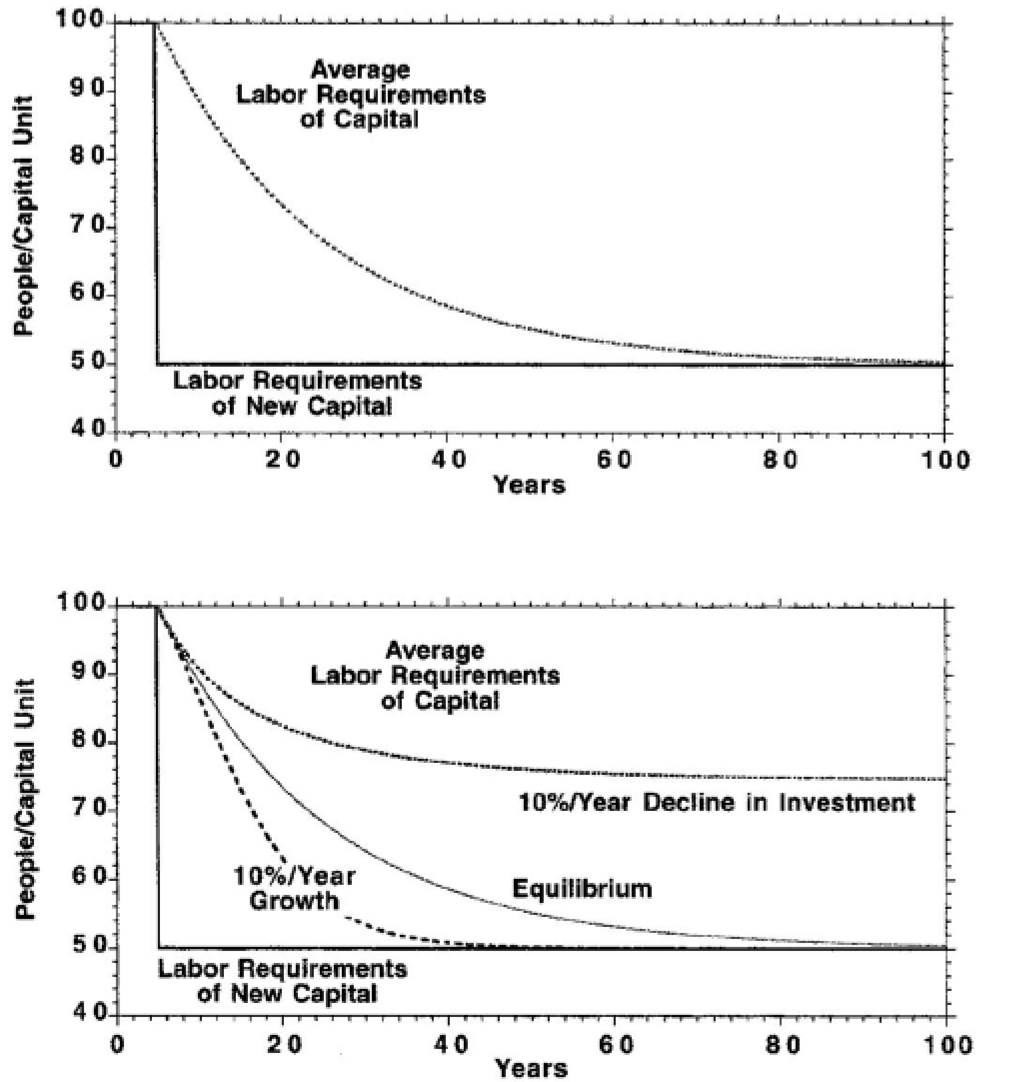
Example: Coflow to track labor requirementss embodied in capital stock

Capital = machines or other production factors, not money

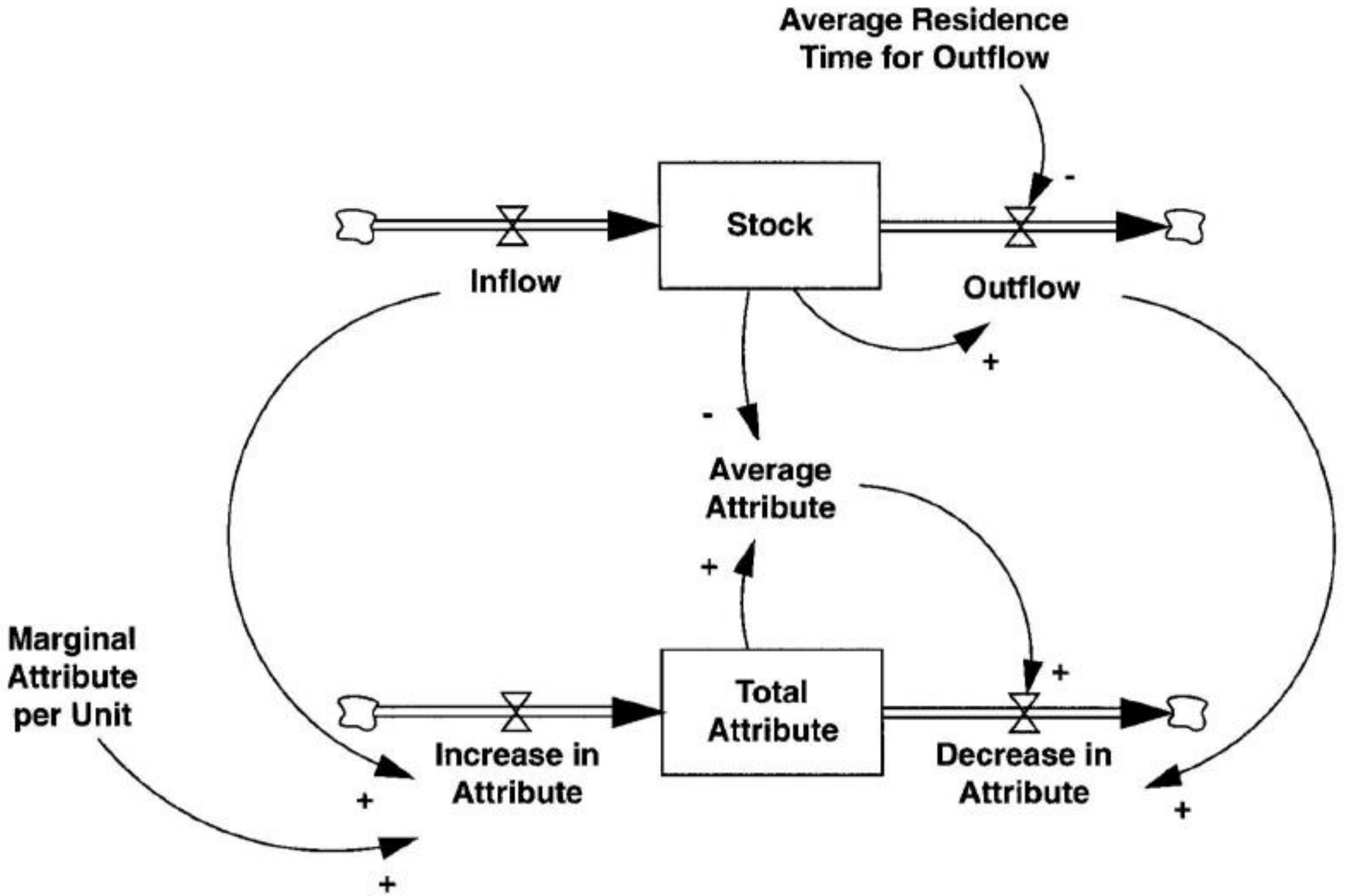


Coflow to track labor requirementss embodied in capital stock

- New machines appear that require 50% less employees
- Bottom: 10% increase or decline in investments
  - Declined investments mean that company can not renew its machines



Generic coflow structure



Integrating coflows and aging chains

- When the material flow is a higher order system, coflows to compute attributes must follow the same structrure

Example: Integrating coflows and aging chains