MSCI 311 – Organizational Design & Technology

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7. Ashby’s Law of Requisite Variety

Outline

- Basic concepts
  - Variety, Requisite variety
  - Information & uncertainty
    - Information theory (Shannon's mathematical theory of communication)
- Organizational applications
  - Contingency theory findings
  - Generic design strategies
  - Just-in-time production

Basic concepts

- Goal-directed dynamic systems
  - Systems regulate/control their output by responding to disturbances
    - From the system's external environment
    - From internal sources within the system
    - E.g., driving a car
  - Negative feedback
    - E.g., thermostat

- Process of regulation
  - Example: “a” is the desired output (i.e., goal)
    - For every disturbance (D), the system must generate a response (R) to maintain “a” as the output (O)

		R: x	R: y	R: z
D	1	b	a	c
D	2	a	c	b
D	3	c	b	a

		R: x	R: y
D	1	b	a
D	2	a	c
D	3	c	b

- Process of regulation
  - Example: “a” is the desired output (i.e., goal)
    - For every disturbance (D), the system must generate a response (R) to maintain “a” as the output (O)

Disturbance Variety $V_D = 3$

Response Variety $V_R = 3$

		R		
		x	y	z
D	1	b	a	c
	2	a	c	b
	3	c	b	a

Output Variety $V_O = 1$ state (always “a”)
System is stable

		R	
		x	y
D	1	b	a
	2	a	c
	3	c	b

- Process of regulation
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		R		
		x	y	z
D	1	b	a	c
	2	a	c	b
	3	c	b	a

Disturbance Variety V_D= 3

		R	
		x	y
D	1	b	a
	2	a	c
	3	c	b

Response Variety V_R= 2

Output Variety
V_O> 1 state (a, b, or c)
System is unstable (out of control)!

- Variety
  - The number of possible states of a system (and their relative probabilities)

- Ashby's law of requisite variety
  - "Only variety can destroy variety"

    (destroy = absorb, handle, cope with, etc.)
  - Requisite Variety
    - Minimum variety of system responses (V_R) <u>required</u> to cope with all incoming disturbance variety (V_D) and control output variety (V_O) within desired limits
      - (Note: to maintain stability, the average time for the system to respond to disturbances should also be less than the average time between disturbances; i.e., not just having enough responses available, but also being able to respond quickly enough.)
    - $V_R \geq V_D$ to maintain stable output
    - $V_O \geq V_D / V_R$
  - E.g., E-mail spam filtering
  - E.g., Game of chess

- Process of regulation (cont'd)
  - More examples

Extra, redundant responses

		R				
		x	y	z	r	s
D	1	b	a	c	a	b
	2	a	c	b	b	c
	3	c	b	a	c	b

Violation of Ashby's Law? (only 2 responses handle 3 disturbances)

- System does not distinguish between D1 and D3; as far as it is concerned, they are the same.

(E.g., thermostat turns on heater if temp.<20C; does not distinguish between 19C, 18C, 17C… etc.)

- Has to do with how the system "perceives" its disturbances. At what level of detail/precision are disturbances defined?

- Set of available responses R determines what the system perceives as a disturbance D (i.e., the system enacts/structures its own environment)

		R	
		x	t
D	1	b	a
	2	a	b
	3	c	a

- Process of regulation (cont'd)
  - More examples

$V_R < V_D$
But:

D	R		
	x	y	z
1 (high prob.)	b	a	c
2 (high prob.)	a	c	b
3 (high prob.)	c	b	a
4 (low prob.)	d	b	c
5 (low prob.)	c	d	b
6 (low prob.)	b	c	d
:	:	:	:

- Choose to handle only high probability disturbances
- Usually stable (V_O= a)

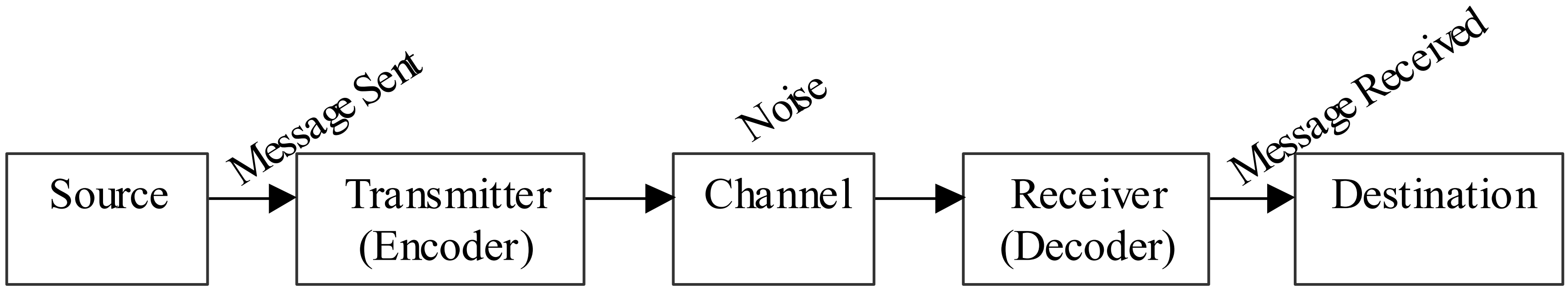
- Choose not to handle low probability disturbances
- Sometimes unstable (V_O= b,c,d…)

- Risk analysis: Trade-off between the costs & benefits of additional responses to handle low probability events
- Depends on relative impact/risk of the disturbances
(e.g., earthquake preparedness; low probability, but huge impact)

- Relationship between variety & uncertainty
  - Both concepts deal with the amount of complexity and change encountered by a system
  - Both are based on mathematical “Information Theory”
    - Claude Shannon & Norbert Weiner
  - Uncertainty is a measure of the amount of information needed to know the state of a system precisely
    - Uncertainty is proportional to the variety of the system
    - As variety ↑’s, uncertainty ↑’s, and amount of information needed to eliminate uncertainty ↑’s

A bit of background on mathematical information theory

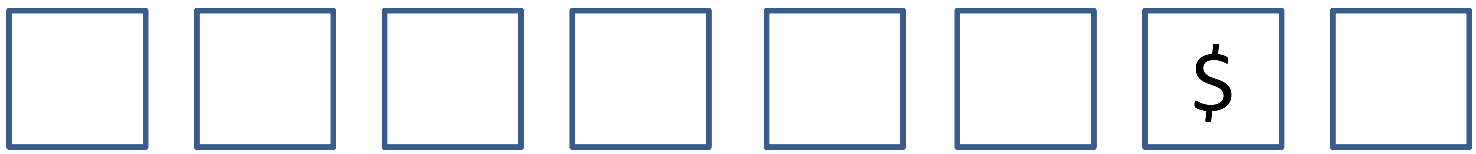
- Claude Shannon's model of the communication process



- Communication = transmission of a message, <u>selected from a set of possible messages</u>
  - Destination experiences uncertainty about which message from the set has been sent
  - Communication works when the message sent by the source, is correctly identified at the destination

- Information & uncertainty
  - Uncertainty
    - A set of possible events may occur, with some probabilities
    - E.g., toss two coins: HH, HT, TH, or TT? (p=0.25 each)
    - Which outcome will actually occur?
  - Information reduces uncertainty
    - E.g., told that one coin is a 2-headed coin
      - Now only 2 possibilities: HH, HT (p=0.5 each)
      - Information has reduced uncertainty about the outcome
      - Set of possibilities reduced from 4 to 2
    - 1 Bit of information reduces the number of equally probable uncertain events by half
  - Amount of information is proportional to amount of uncertainty reduced

- Information measurement ("Shannon entropy")
  - E.g., find money in one of 8 boxes with the minimum number of binary (Y/N) questions



  - Information in bits = $\log_2$(array size)

    = Amount of information needed to reduce uncertainty to zero

    - E.g., $\log_2(8) = 3$ bits
    - Need to ask 3 binary (Y/N) questions (on average)
  - For events with non-equal probabilities

$$\text{Information (in bits)} = -\sum p_i \log_2 p_i$$

- Binary communication codes
  - Strings of binary digits (i.e., bits: 1’s, 0’s) used to denote letters of alphabet
    - Min. 5 bits needed to discriminate among 26 letters
      - i.e., $\log_2(26) = 4.7$ bits
    - E.g., 00001 = A, 00010 = B, 00011 = C … etc.
  - Sender encodes text message as a string of 1’s, 0’s
    - Receiver decodes by referring to a table of codes to reconstruct the message
    - Multi-level nested system of encoding/decoding
      - E.g., person A types text message; phone translates into 1’s,0’s, voltage level signals, etc., ... eventually process reverses so B receives text message
  - Note: two slightly different (but related) meanings of “bit”
    - Quantitative measure of the amount of information needed to discriminate among a set of items (i.e., the amount of uncertainty)
    - Binary digit in communication codes
    - Relationship:
      - Binary digits sent during communication enable the receiver to select the correct message from a set of possible messages.
      - So the receiver gains information (equal to the number of bits sent), which reduces uncertainty with respect to the set of possible messages.

- Terminology: Variety vs. uncertainty (or "entropy")?
  - Mathematically identical
    - Both measure system complexity
      - # of possibilities (i.e., array size) & their relative probabilities
      - Measured as bits of information, or just by counting the number of possible states
    - As variety ↑'s, uncertainty ↑'s, and amount of information needed to eliminate uncertainty ↑'s
  - Why different terminology?
    - Variety: Same construct used to describe disturbance states (V_D), response states (V_R), and output states (V_O)
    - Uncertainty: reflects experience of receiver
      - Makes sense for disturbance; makes less sense for response and output states

Organizational applications of Ashby's Law

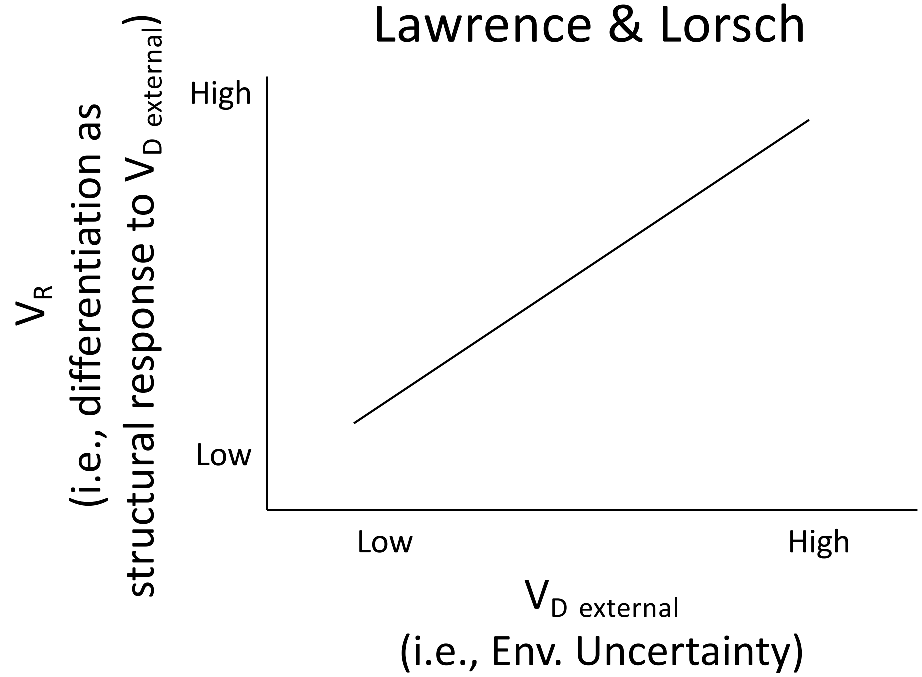
- Sources of variety in organizations
  - First need to choose appropriate system boundaries and level of analysis
    - E.g., organization, department, job, task
  - Disturbance variety (V_D)
    - External variety ($V_{D\ External}$)
      - E.g., customer demand; consumer online behaviour; supplier quality; competitive products
    - Internal variety ($V_{D\ Internal}$)
      - E.g., employee error; machine breakdown

- Response variety (V_R)
  - E.g., employee or process flexibility; personalization analytics/algorithms; quality/error inspection and repair; machine maintenance; new product development strategy
- Output variety (V_O)
  - E.g., variation in product quality; variation in sales volume relative to goal
- Law of Requisite Variety
  - $V_R \geq V_D$
    - i.e., $V_R \geq V_{D\ External} + V_{D\ Internal}$
  - If not, then V_O must increase ($V_O \geq V_D/V_R$)

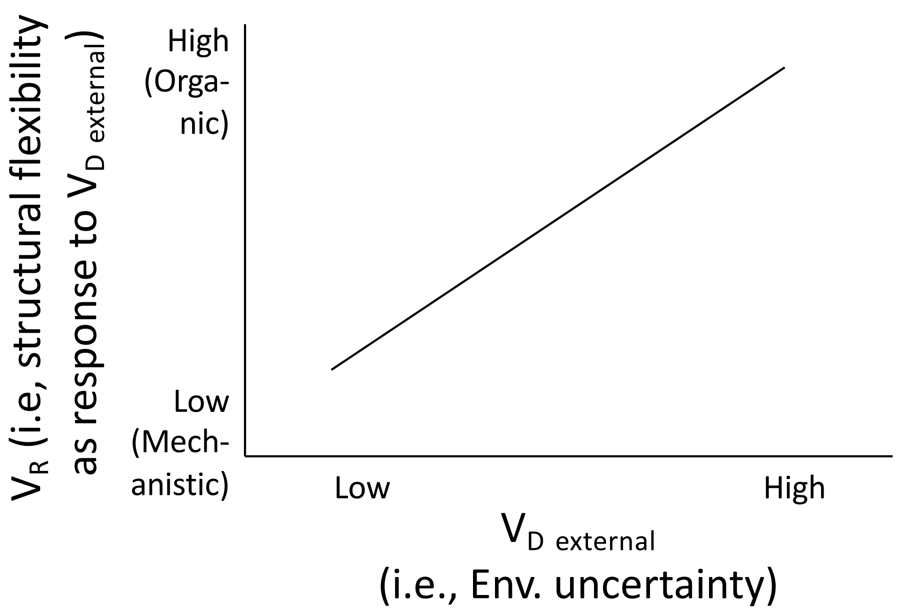
- Using Ashby's Law to interpret organizational theory & research findings
  - Empirical studies of organization-environment interaction
    - Burns & Stalker
    - Lawrence & Lorsch
  - Bureaucracy
    - Reduces variety (e.g., rules, procedures)
    - Creates variety (e.g., Merton's model)
  - Organizational size & formalization
  - Age & formalization
  - Organization grouping
    - Group tasks that generate high variety for one another
    - I.e., group variety source & recipient within same organizational units (same department, job, etc.)

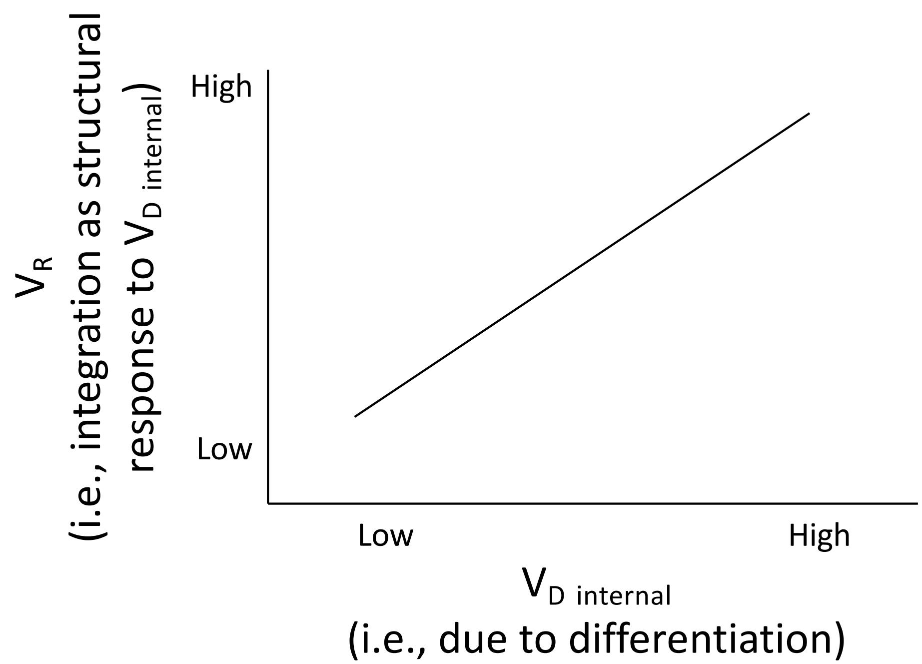
Ashby’s Law interpretation of contingency studies of organization-environment interaction:

Lawrence & Lorsch

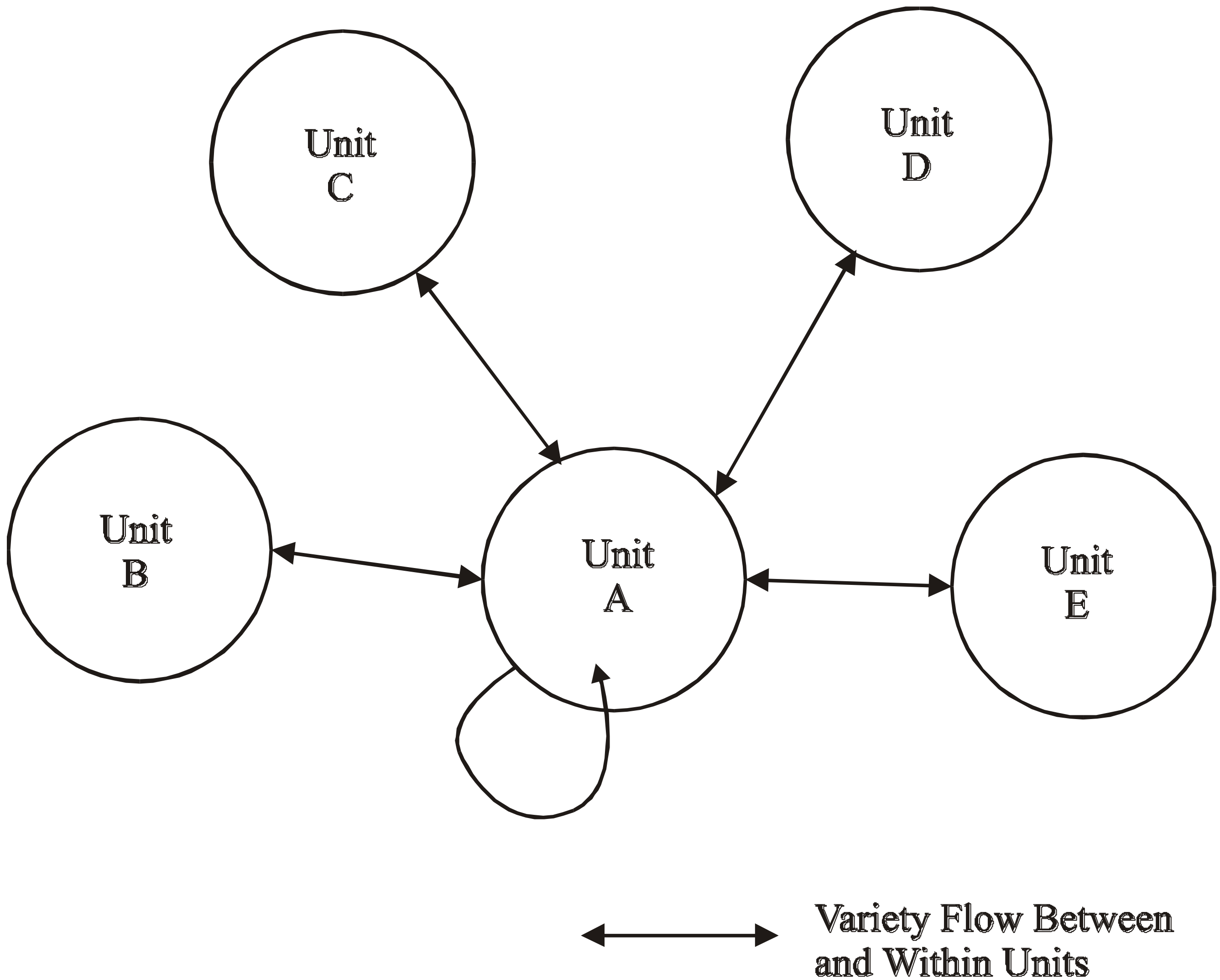


Burns & Stalker

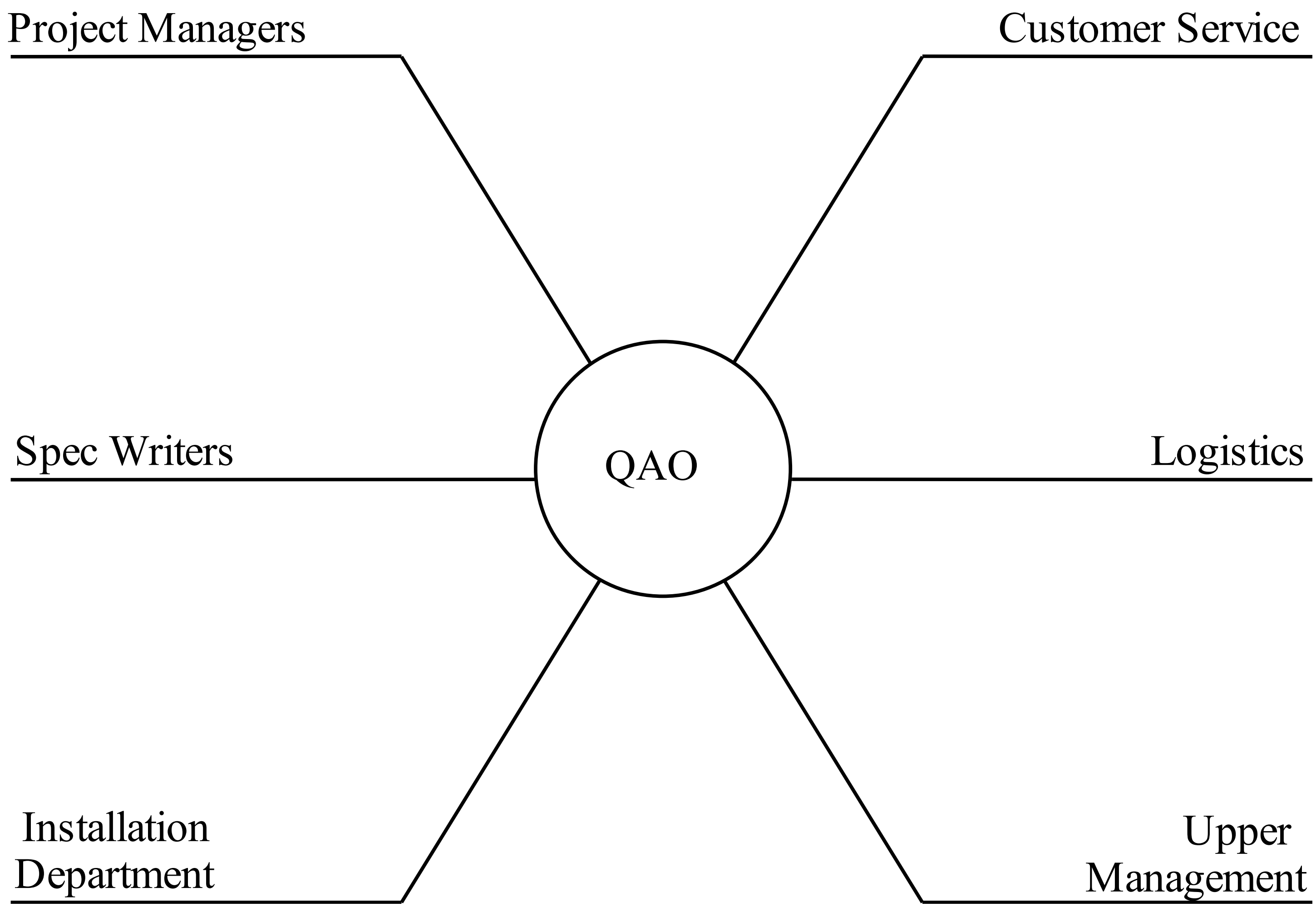




- Measuring “variety”
  - Counting the number of system states precisely
    - Using measures from information theory
      - E.g., 8 possible states requires 3 bits of information
    - or just by counting the number of possibilities
  - Big data analytics methods
    - Track data corresponding to relevant V_D, V_R, V_O
    - (Assumes relevant data are available; but not all relevant V_D, V_R, V_O are easily quantifiable)
  - In organizations
    - Examine unit-to-unit interactions
    - Positive vs. Negative interactions
    - E.g., “echo method”


Unit
C
Unit
D
Unit
B
Unit
A
Unit
E
Variety Flow Between
and Within Units

– Example: Echo Method



- Generic organizational design strategies based on Ashby's law
  - What to do if there is more disturbance variety than the org. can handle?
    - i.e., what if $V_R < V_{D\ external} + V_{D\ internal}$?
  - 3 basic strategies

  1) Reduce amount of disturbance variety (V_D)
    - Grouping input variety into fewer, general categories
      - E.g., rules, constraints
    - See also notes on "Reducing environmental uncertainty" from Environment section

2) Increase response variety (V_R)

- Increase process/organizational flexibility
- Increase information processing capacity
  - But note: computers often amplify variety
- See also notes on "Adapting to environmental uncertainty" from Environment section

3) Increase output variety (V_O)

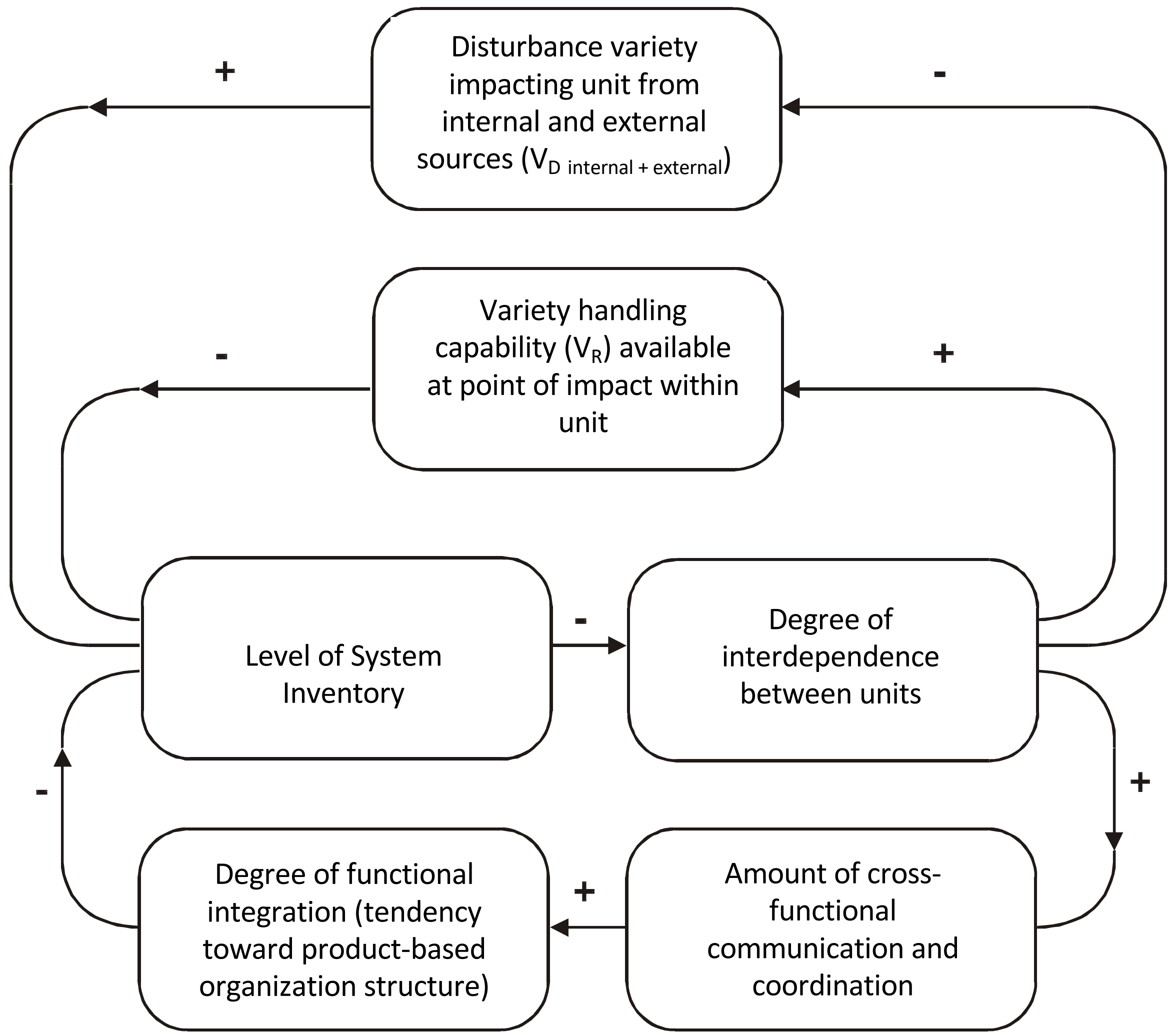
- $V_O \geq V_D / V_R$
- I.e., increase tolerance on outputs (e.g., accept certain level of customer dissatisfaction due to limited product offerings)

– Note: often most efficient to first reduce V_D as much as possible/reasonable; then increase V_R to handle remainder

- V_R strategies often generate additional V_D as a side-effect
- E.g., flexible technology adds complexity, maintenance issues, etc.

- Example: Study of Just-in-Time/Lean production
  - Inventory = buffer, absorbs variety between interdependent activities (i.e., a source of V_R)
    - Reduced inventory: reduced V_R
    - To operate with low inventory: need to reduce V_D and/or increase V_R
      - (Assuming increased V_O is an undesirable option)
  - Successful JIT firms
    - Reduced inventory correlated with reduced variety (V_D)
      - E.g., reduced range of product options, etc.
    - Increased variety handling capability (V_R)
      - E.g., increased machine flexibility, etc.
    - Changed org. design to improve communication & coordination to handle increased task interdependence
  - Many firms did not make needed adjustments
    - Result: inventory soon returned to pre-JIT levels

– A model of the organizational impact of inventory reduction in Just-in-Time production



Categorization of "Helpful" echo comments made about the production function

Comment Category	Number of Companies
Manufacturing Processes	11
"We've got the ability to change tools on the line very quickly if we have to."	
Cells/Plant Layout	10
"We made a cell which was almost universal, so we can run almost all of our boxes through one and the same cell."	
Production Control	10
"We use balanced production rates."	
Inventory/Throughput Time Reduction	10
"We've reduced our work-in-process drastically by keeping the flow going from the raw materials right down to the finished goods."	
Internal Communication	9
"The open office concept helps in the area of communication. Everyone is sitting together."	
Kanban/Material Flow Control Techniques	7
"We have a Kanban type pull system which allows production to adjust to demand fluctuations on a continuous basis."	
Work Environment/Treatment of Workers	6
"We are a stable company in this area. We have not, nor will we ever have a layoff. No employee will ever be laid off."	
Focused Factories/Product Organizational Structure	6
"One of the big things was to break into focused factories. So the implementation groups were set up based on products, and they later became responsible for their own little focused factory, little mini-plants within the plant."	
Worker Flexibility	6
"You get into a multiple disciplined work force."	
Quality	6
"We perform continuous statistical quality sampling on all processes to ensure that only good quality parts move on to the next process."	

Summary

- Ashby's law describes regulation of output behaviour of goal-directed dynamic systems
- General law
  - Applicable to diverse systems, at many different levels of analysis
  - But: abstract, so need to define "variety" for each unique situation
- Helps understand organization design alternatives
  - Explains contingency theory findings
  - Organize to match V_D to V_R for a given level of V_O
  - Explains logic of JIT production