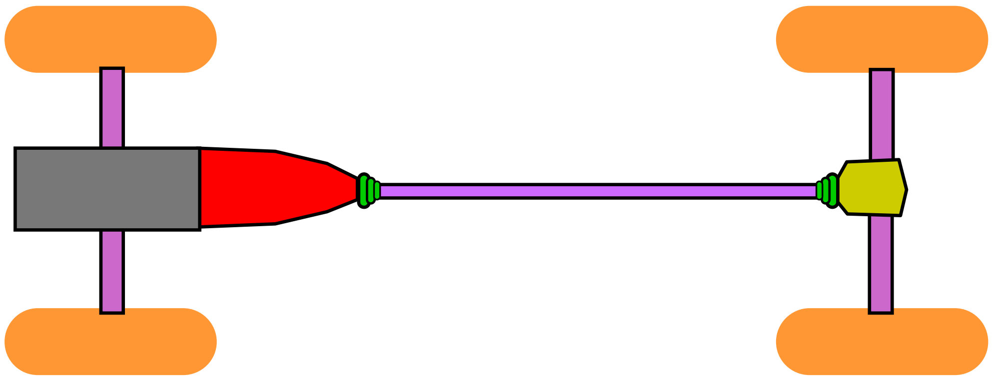
Product Architecture

- Goals of this class
  - understand product architecture and its role in product development
  - see the effect of different architectures on some AITL issues
  - look at examples of different architectures

Definition of Product Architecture

- Product architecture is the scheme by which the functional elements of the product are arranged into physical chunks and by which the chunks interact
- This definition links architecture to system-level design and the principles of system engineering
- Architecture also has profound implications for how the product is designed, made, sold, used, repaired, etc
- Architecture makes its influence felt during assembly

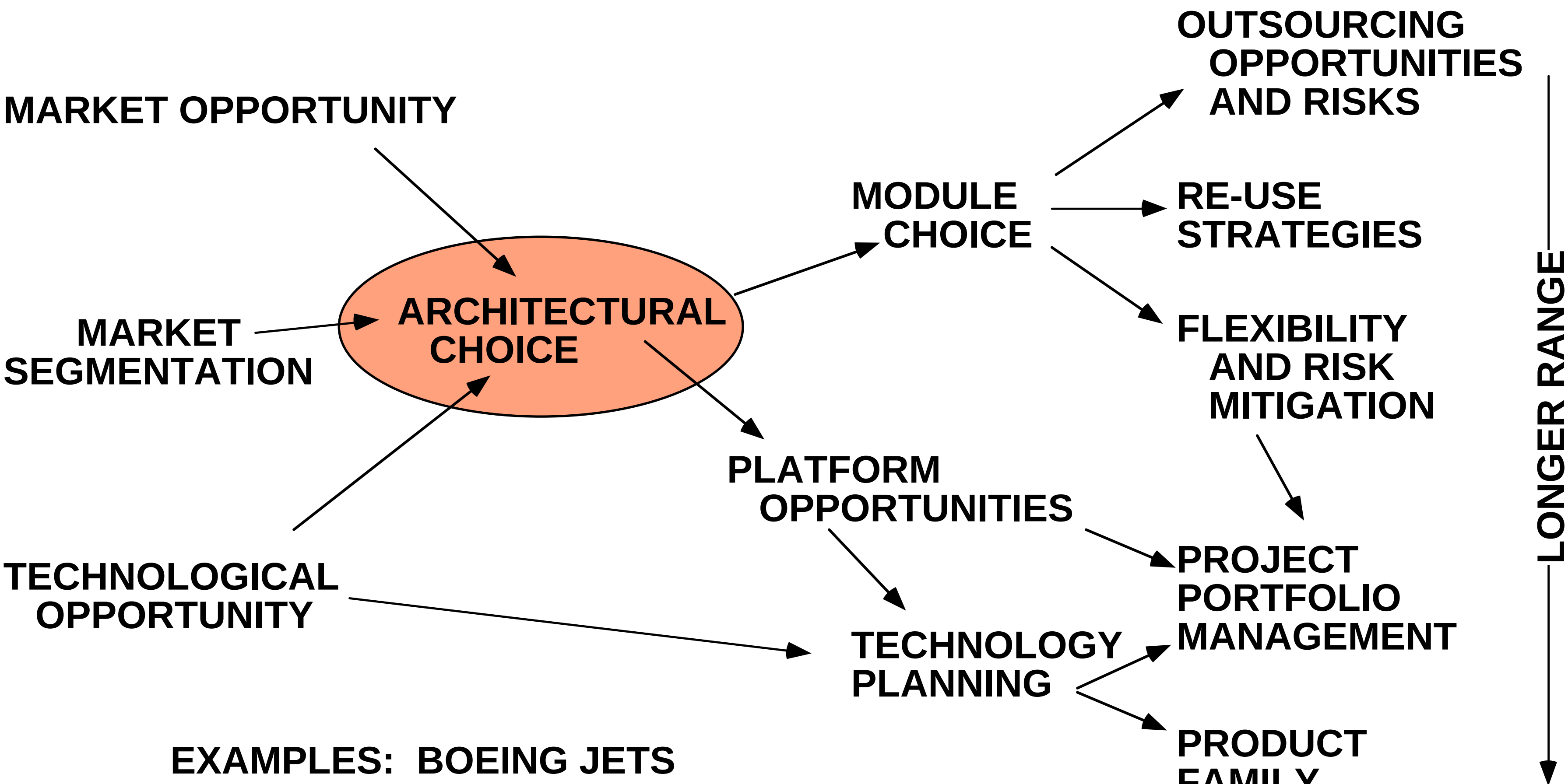
Front and Rear Wheel Drive Architectures



Same elements, arranged differently

fwd & rwd

Role of Architecture in Product Development



EXAMPLES: BOEING JETS
DENSO PANEL METERS
TELEMECHANIQUE CONTACTORS
B & D HAND TOOLS

architecture

Architecture's Influences

- During product development

- How families and platforms are structured
- How functions are realized
- How reuse and standardization are accomplished
- How development work is divided up
- Where subassembly and module boundaries are
- Where DFCs go
  - In the product
  - In the organization
  - Along the supply chain

Architecture's Influences - 2

- During production system design

- Assembly sequences
- Reuse of facilities and knowledge
- Planning for flexibility
- Sharing of facilities to match capacity to demand

Architecture's Influences - 3

- During manufacturing and assembly
  - Where production happens
  - How customer orders are fulfilled
  - How unpredictable demand patterns are met
- During use
  - How service is delivered
  - How the product is updated
  - How the product is recycled

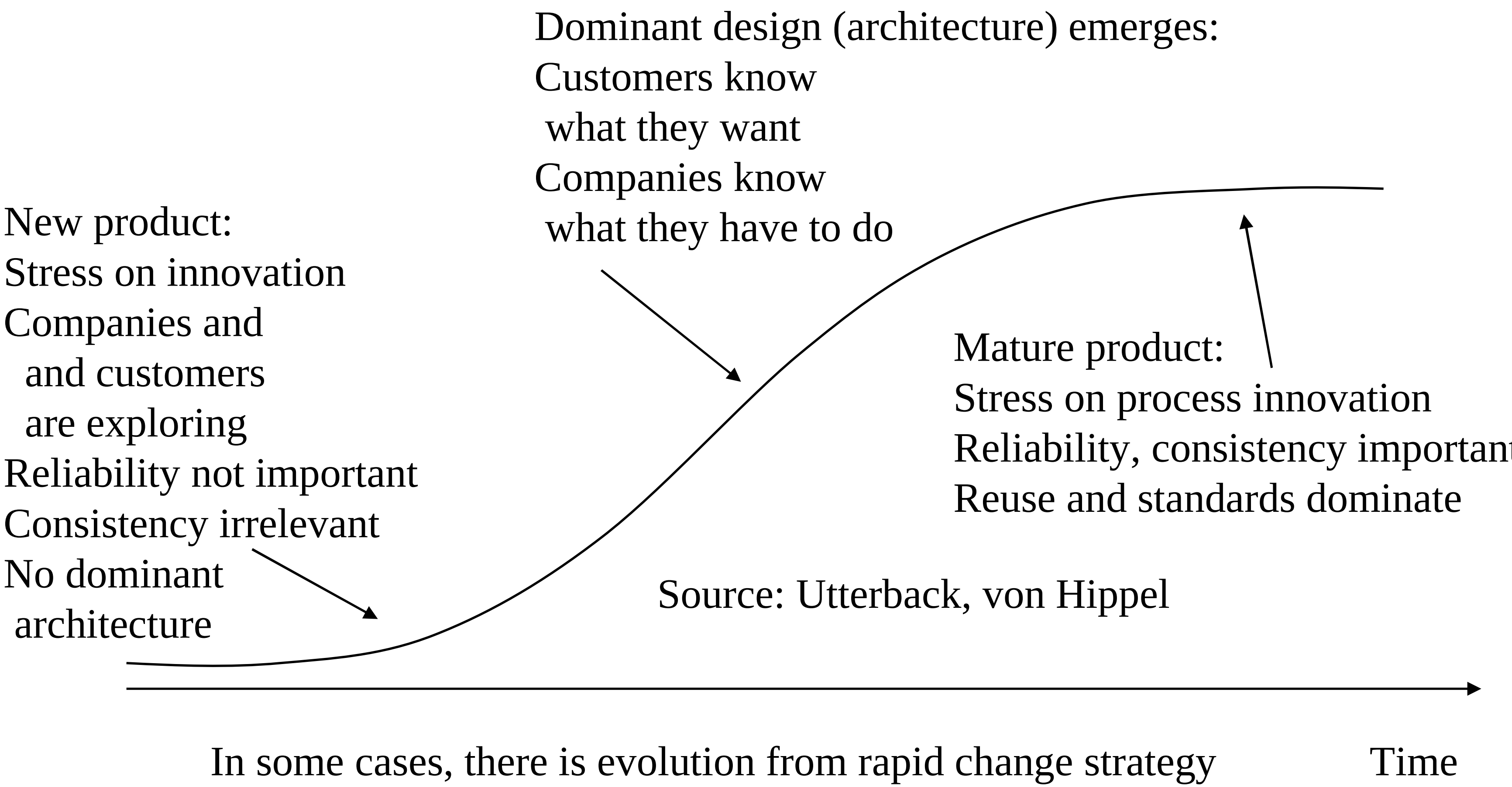
Integral and Modular Architectures

- Integral = functions shared by physical elements
- Examples...
- Some reasons integral is used...

- Modular = each function is delivered by a separate element
- Examples...
- Some reasons modular is used...

Is either kind of architecture “better” than the other?

Architecture and the "S-Curve"



In some cases, there is evolution from rapid change strategy to high variety strategy [Sanderson and Uzumeri] over time

Architecture may evolve from integral to modular [Christensen] or not!

Integral/Modular Comparisons

Modular	**Integral**
Chunks may be integral inside but are independent from each other functionally and physically	Chunks may be integral inside and interdependent among each other
Standard, pre-designed interfaces can be used that can remain the same even if internal characteristics change	Interfaces are tailored to the chunks and are dependent on functional behavior
Modules can be specialized to their individual contributions to overall function and can be used interchangeably	Chunks are tailored to their application and cannot be interchanged without requiring changes to other chunks
Unpredictability of module choice requires over-design elsewhere to accommodate possible mismatches	Overall design can be optimized for a predictable set of functions and implementations
Standard interfaces are physically separate from the module and thus waste other design resources such as space or weight; interfaces are "weak"	Interfaces can be integral to the chunk, saving space or weight; interfaces are "strong"
Interface management, if planned properly, can provide flexibility during production	Interface management occurs entirely during design and is frozen; it is not aimed at flexibility after design
Business performance may be favored	Technical performance may be favored

Adapted from J-P MacDuffie "Automotive "Build to Order" - The Modularity - e-Business Link" IMVP talk 9/27/00

Integral/Modular Options*

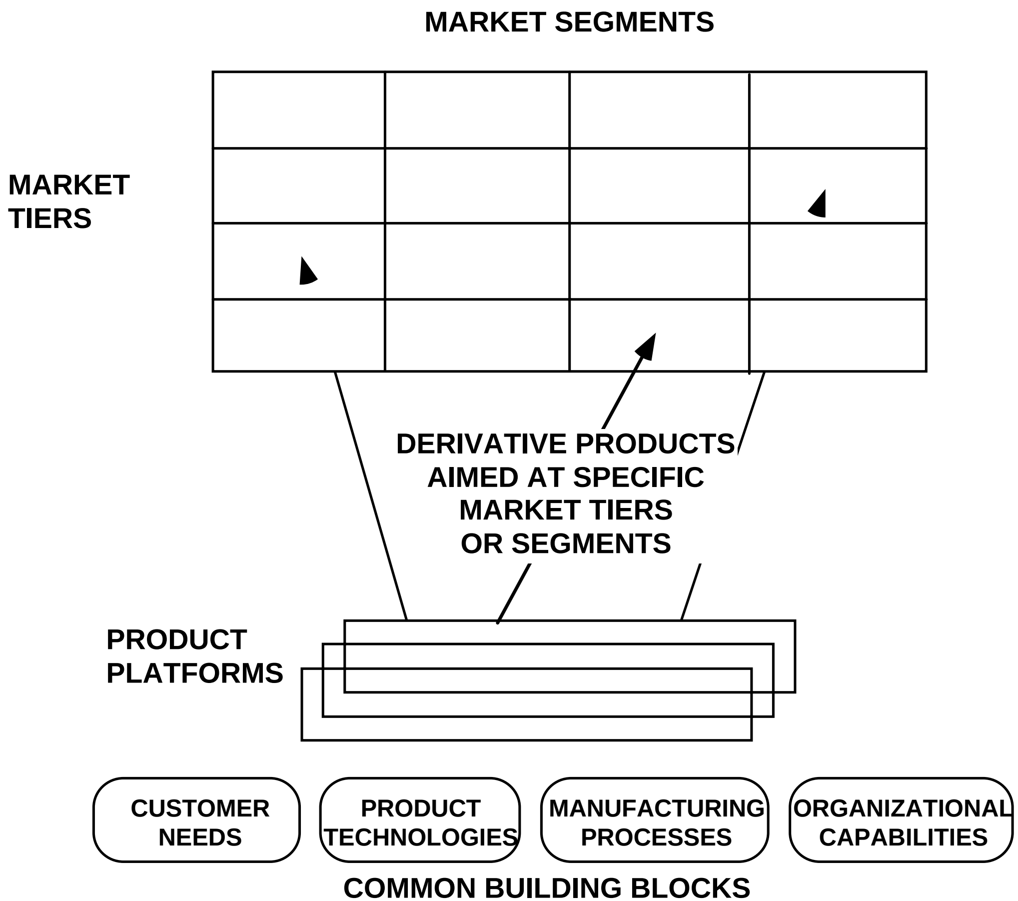
	Each function is realized by	Many functions are realized or shared by
One part	VLSI Modular architecture	Cast or molded parts Transaxle case Integral architecture
Many parts	Typical simple assembly Integral "chain" or "holistic" architecture	Most assemblies Car door Integral or coupled architecture

Ulrich and Eppinger

Mixed architectures are the most common, in which some functions are realized by some options and others by other options

*Tim Cunningham, MIT PhD thesis"Chains of Function Delivery: A Role for Product Architecture in Concept Design" Feb 1998

Lehnerd-Meyer Platform Concept



Courtesy of: THE POWER OF PRODUCT PLATFORMS by Marc H. Meyer and Alvin P. Lehnerd, (c) 1997 The Free Press. Used with permission.

Example Platform

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Source:
Figure 14-15 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

Originally one mechanical board and one circuit board using through hole electronics
Later one board for all using surface mount electronics
Outside shell changed to meet different style and customer needs while guts stay the same

Denso Panel Meters: Architecture and DFA Driven by JIT in Assembly

Denso makes many kinds of panel meters for Toyota.
Toyota orders different ones in different amounts every day.
ND designed an "assembly family" of meters and can make any quantity of any kind at any time by selecting the right parts. Assembly interfaces were standardized for all parts. The result is 'assembly-driven manufacturing."

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Source:
Figure 1-7 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

Each path yields a different kind of meter.

288 different kinds of meters can be made with no additional cost or delay, and almost no changeover time.

Panel Meter Family Assembly Architecture

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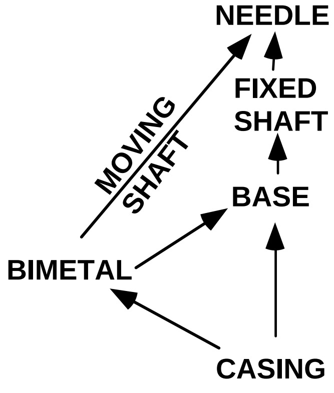
Source:
Figure 14-11 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

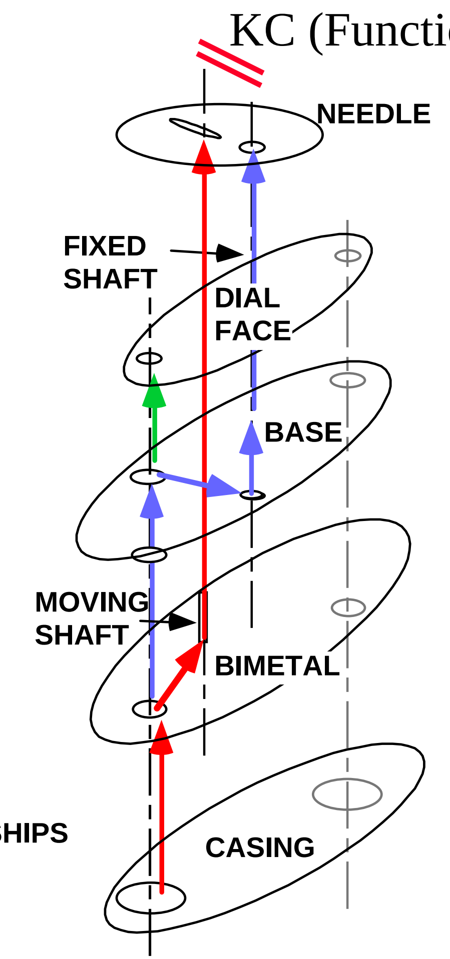
ONE INSTANCE OF THE PANEL METER

SEVERAL INSTANCES OF THE PANEL METER

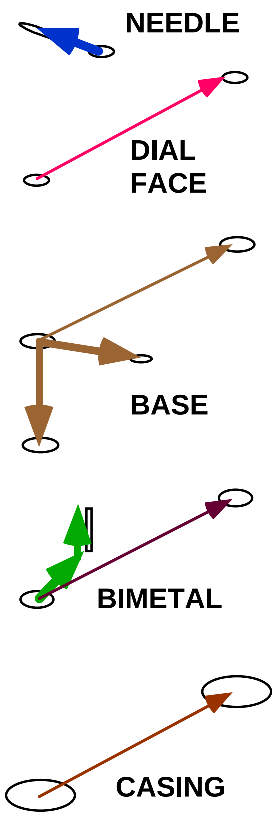
Panel Meter Assembly Architecture and DFC



(a) BASIC PART-PART RELATIONSHIPS



(b) DIMENSIONAL FLOW BETWEEN PARTS

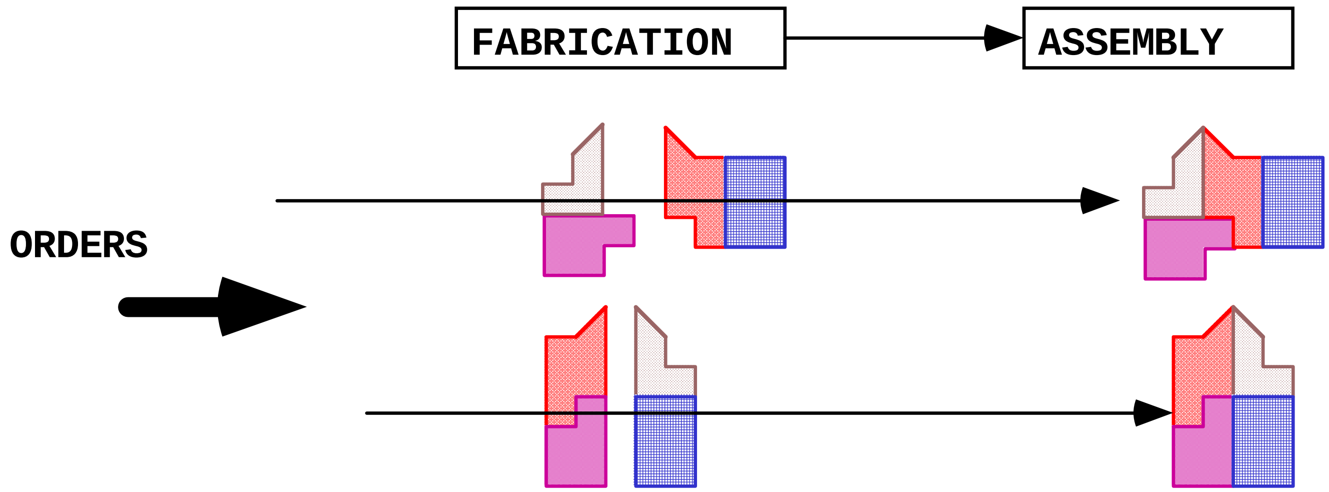


(c) DIMENSIONAL FLOW WITHIN PARTS

Panel Meter KCs

- Function of each meter
  - Alignment of parts stack
  - Placement of moving pin and stationary pin
- Function of the family
  - Negotiation of family variety dimensions
  - Common architecture along stack of parts
  - Same DFC for each family member
  - Each family member mechanizes each function the same way using similar part designs
  - All inter-part mates standardized for each version of a part type or placement on the stack

Fabrication-Driven Manufacturing

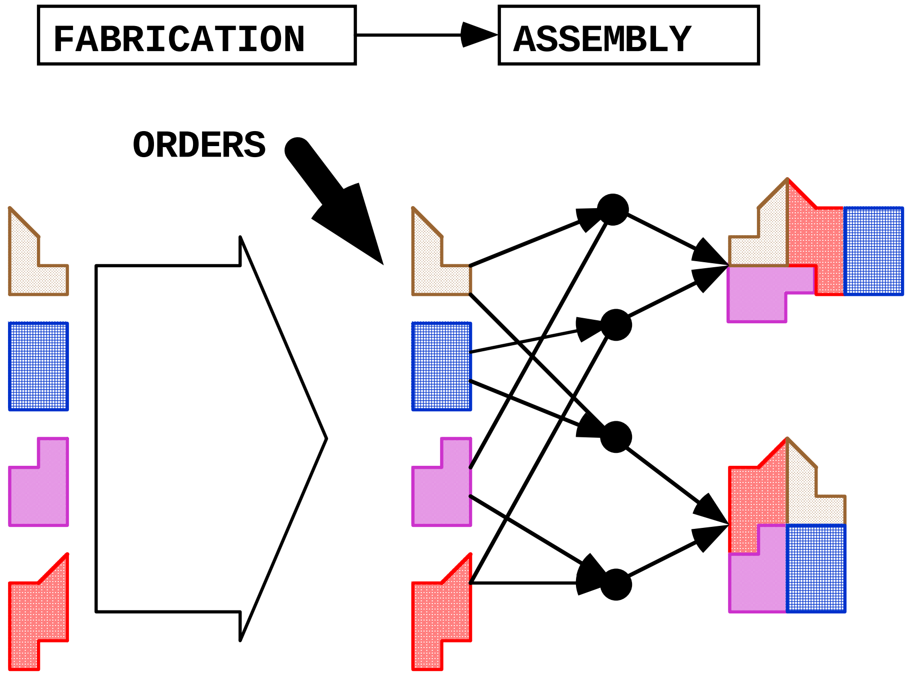


RELIES ON FABRICATION TO EXPRESS MODEL MIX AND ACHIEVE FLEXIBILITY:

IN RESPONSE TO ORDERS, COMPLEX PARTS ARE MADE AND THEN ASSEMBLED INTO FINAL ITEMS.

THIS IS A LOW BANDWIDTH METHOD BECAUSE FABRICATION TAKES SO LONG.

Assembly-Driven Manufacturing (Denso Panel Meters)



RELIES ON ASSEMBLY TO EXPRESS MODEL MIX AND ACHIEVE FLEXIBILITY:

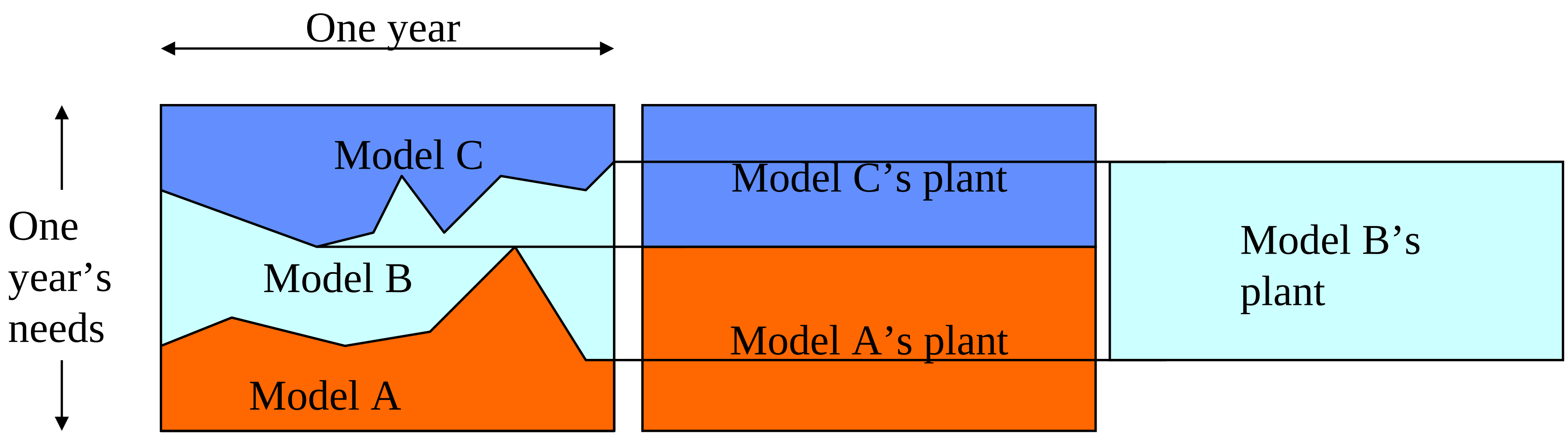
SIMPLE PARTS ARE MADE TO STATISTICAL TRENDS. IN RESPONSE TO ORDERS, ITEMS ARE ASSEMBLED.

THIS IS A HIGH BANDWIDTH METHOD BECAUSE ASSEMBLY HAPPENS SO QUICKLY.

Denso's Flexibility Dimensions

- Volume change (market controls)
  - aggregate, distribution within aggregate
- Product variation (customer controls)
  - configuration
  - size
  - model
  - type
- Design change (Denso controls)
  - minor, model, next generation

Demand Fluctuations



One switchable plant can make all models and needs only full year's Capacity - Denso does it with product design

Three focused plants must each have max capacity anticipated for its product

Lightweighting Cars

- Steel approach
  - high strength steel in small amounts
  - integral design
  - welded
- Aluminum design
  - rely on lower weight material
  - modular design
  - “tinker-toy” assembly

Ultralite Steel and Aluminum Car Bodies

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Source:
Figure 14-3 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

Rib-stiffened Shell

Photo from Am Iron and Steel Inst

Space Frame

Photo from Audi

Airbus: Architecture Driven by Politics

- Airbus Industrie was a consortium that shared revenue and profits according to a work-content formula
- This formula was based on a decomposition of the plane
  - wings to British Aerospace
  - fuselages to Deutsche Aerospace
  - tail sections to CASA (Spain)
  - final assembly and integration to EADS
- The A380 caused problems
  - The wings are too big to transport to Toulouse by air
  - A special handling system was developed for land and water transport

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Source:
Figure 16-33 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

Airbus A319, 20, 30, 40

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Source:
Figure 16-35 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

Commonality, Carryover, Reuse

- A mystery: how could Toyota design cars with so few engineering hours?
  - By outsourcing (1970s-80s)
  - By carrying over parts (1980s-90s)
    - paradox: heavyweight program manager -> parts proliferation
  - By overlapping whole car programs (1990s)
- Toyota's definitions
  - OK to reuse parts the customer doesn't see
  - Reuse of a body shop means reuse of assembly sequence and assembly locators
  - "Whoops! There goes $75M."

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Source:
Figure 14-6 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

Ford Motor Co.

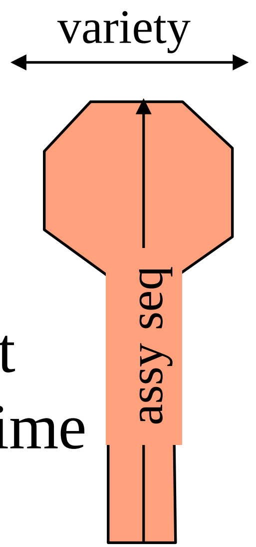
Elements of Carryover and Reuse

- Consistency of interfaces
  - between adjacent parts
  - between parts and tools
  - between parts and fixtures
  - assembly sequence
- Consistency of performance (out of scope for this course)
  - strength
  - materials compatibility
  - dynamics
  - “coherence” as defined by Fujimoto and Clark

Product "Structures"

- Ulrich's types (called architectures)
  - integral (parts are combined)
  - slot (parts share structured common base)
  - bus (parts share unstructured common base)
  - sectional (parts are linked)
- Redford and Chal's
  - integral (parts are combined)
  - differential (parts are separated)
  - stack/serial (Tower of Hanoi)
  - array/parallel (circuit board)

Business-Driven Structures



- "Mushroom product" (Mather)
  - inside/outside or assembly sequence chosen to permit delayed committment or to accommodate long lead time items
  - only a few parts are in the variable set (head of mushroom)
- "Plain vanilla box" strategy (Tayur)
  - similar to mushroom but often focused on inventory management and smoothness of line operations
- Denso panel meters
  - no mushroom or vanilla box segment can be found
  - no base plus variations can be found

How DELL Does It

- Product is highly modular
- Suppliers own inventory until assembly starts
- Order takers know what is in stock
- Order takers know what modules are mutually compatible
- Customers are lured to what is in stock that meets their needs using short delivery time
- There are runners and expediters scouring the earth for parts
- Inventory turns were 6 only 4 years ago vs 20 now
- “Why can’t Detroit be like DELL?”

Volvo's "21 Day Car"

- Cars are delivered to customers 21 days after order
- All high value items are built less than a few hours' transit time from final assembly line
  - Engines, transmissions, seats, instrument panels
- Many mid-value or highly variable items are built in the final assembly plant in nearby shops
  - Steering columns
- There are big stocks of low value parts
- The biggest problem is unpredictable paint quality
  - Only 20 colors and 3 body styles avail
  - Cars are painted "on spec" and picked to meet orders from a one shift size buffer

Volvo's "21 Day Car" - 2

Customer can choose:

- Seats
- Interior colors
- Roof rails
- A/C, cruise control
- Electr windows & mirrors

Random access buffer of ~ 300 painted bodies = 8 hrs worth - 3 body types, 20 colors = 5 duplicates of any one item

Car assigned
To customer
4 hours before
Final assy starts

165K/yr
2 shifts=
~1.5 min/car

Weld (4-6 hrs) → Paint (4-6 hrs) → Final assembly (8 hrs) → 3 hrs

Specific order build starts

Seat plant → 4 hrs → 5 hrs

Source: Mr Etienne De Jaeger, Volvo (Ghent)

Telemechanique Motor Contactors: Architecture Driven by Customers

CONTACTORS START AND STOP MOTORS FROM WATTS TO KWATTS

THE FAMILY IS A SET OF SIMILAR-LOOKING ITEMS WITH SIZE α WATTS

BASIC IDEA: MODULES ARE CUSTOMER'S VIEW

SUBASSEMBLIES ARE MANUFACTURER'S VIEW

THE CUSTOMER PUTS THE PRODUCT TOGETHER FROM MODULES

THEREFORE: DESIGN THE "BUYING EXPERIENCE" FIRST

DESIGN THE CATALOG, CROSS-INDEX, LINK TO USES

DETERMINE THE CORRECT MODULES

STANDARDIZED MOUNTINGS, TERMINALS, BOXES

THEN DEFINE SUBASSEMBLIES

THEN PLAN THE RANGE OF IMPLEMENTATIONS ACROSS POWER LEVELS

Architecture of Power Tools

Image removed for copyright reasons.
Source:
Figure 14-25 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

CLAMSHELL ARCHITECTURE

Brand “X” late ‘70s
(still used)

Alternate Architecture for Power Tools

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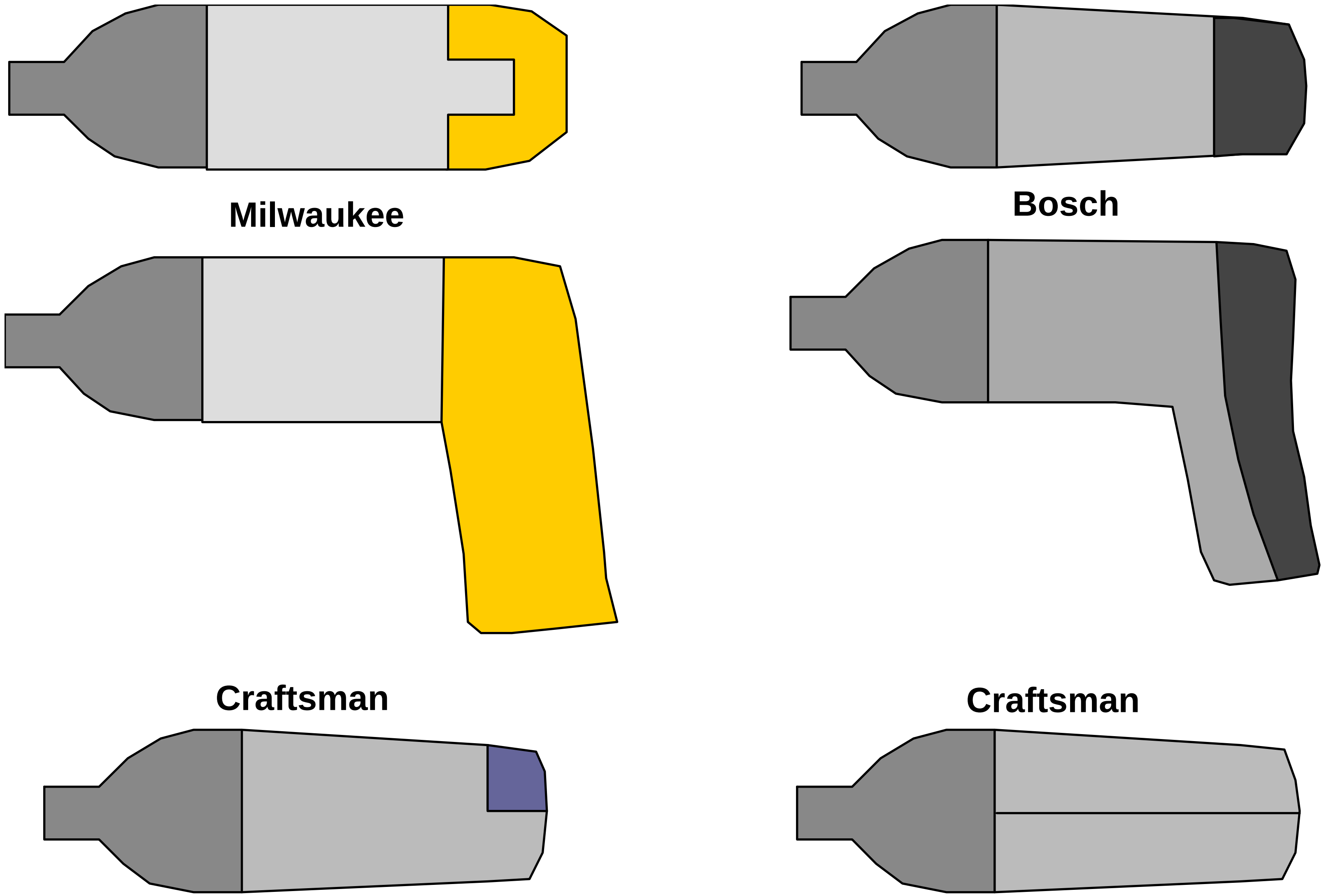
Source:
Figure 14-23 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

AXIAL/STACK ARCHITECTURE WITH COMMON MOTOR MODULE

Black & Decker ~ 1981
(still used)

See Lehnerd, Alvin P, "Revitalizing the Manufacture and Design of Mature Global Products" In Bruce Guile and Harvey Brooks, eds, Technology ad Global Industries, Washington, National Academy Press, 1987.

Drill Architectures



Architecture Tradeoffs for Power Tools

- Clamshell design easy to assemble manually
- Long history of cost reduction
- Can't assemble automatically or robotically
- Stack architecture easy to assemble automatically
- Allows huge economies of scale in motors
- Represents a paradigm shift
- How did Black and Decker accomplish it?
  - a shocking answer

AMP Powerline Splice

- Two use case scenarios
  - how to buy
  - how to make
- Product architecture aligned to both
- Looked great on paper and prototype

Existing Power Line Splice Scenario

PREMADE

PHONE RINGS: SIZE OF CABLE

SELECT TUBE AND INSERTS

CALL FED EX

IN THE FIELD: TRANSPORT SPLICE, GENERATOR, HYDRAULIC POWER SUPPLY, AND PRESS TO SITE

INSERT CABLE AND INSERTS, SQUEEZE

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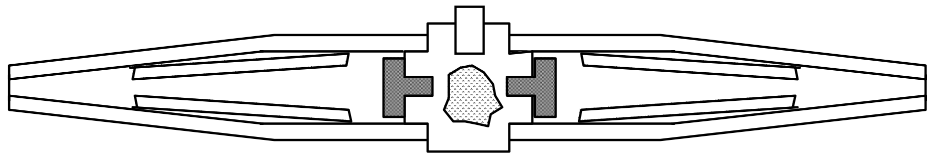
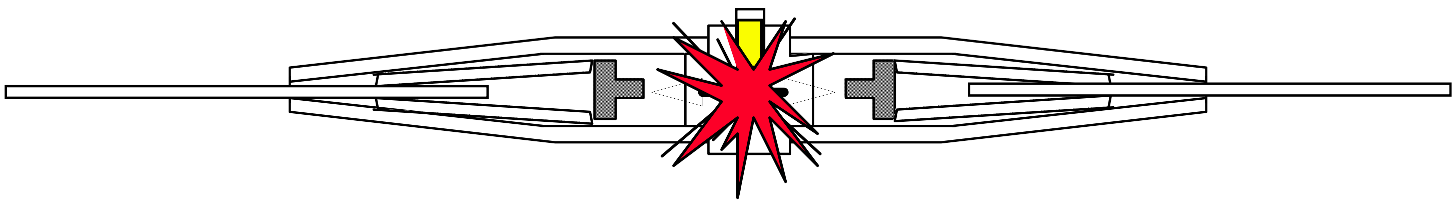
Source:
Figure 14-31 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

New Power Line Splice Scenario

ASSEMBLED SPLICE

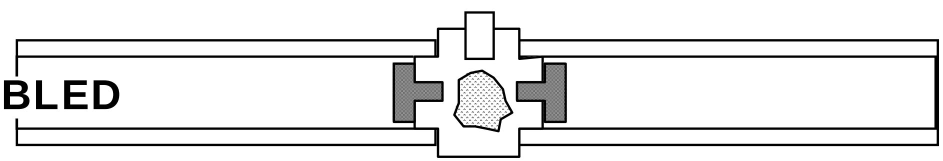


HOW IT WORKS



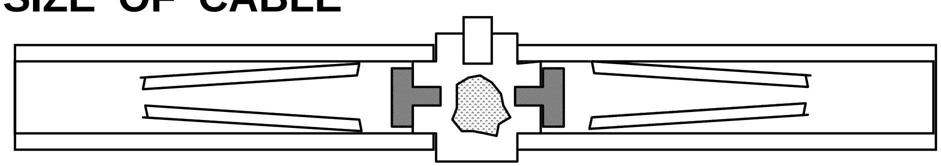
THE BUSINESS CASE

PREASSEMBLED



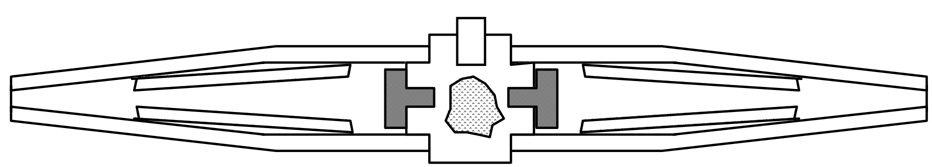
PRICE: $100

PHONE RINGS: SIZE OF CABLE



SELECT JAWS

SWAGE TAPER



CALL FED EX

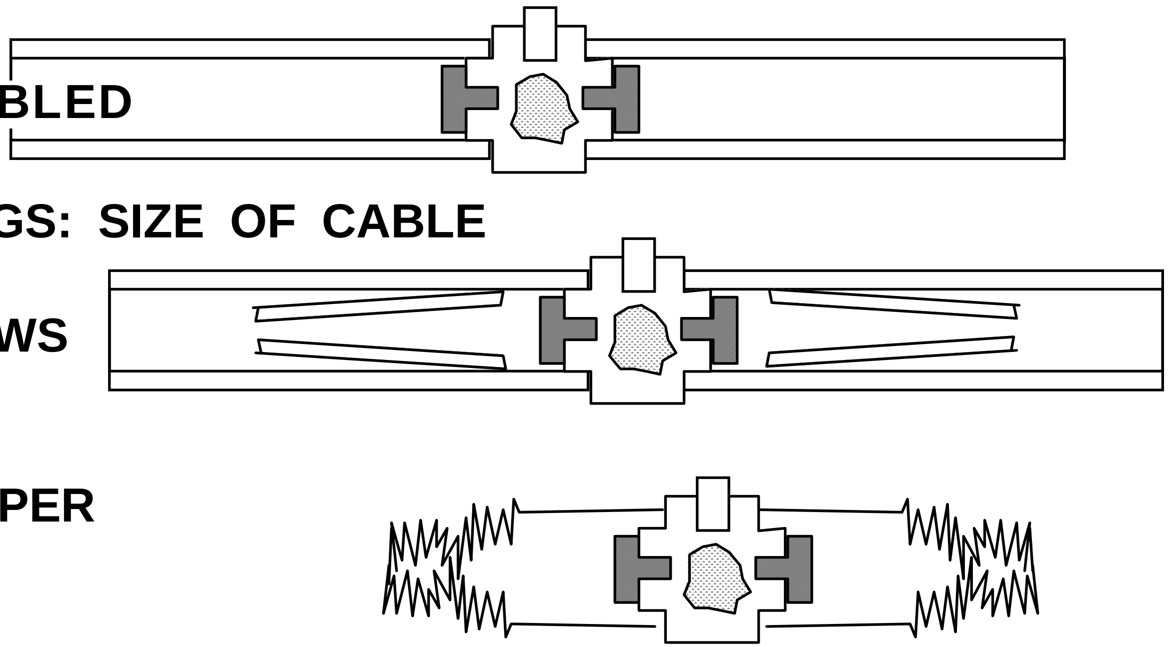
What Happened...

PREASSEMBLED

PHONE RINGS: SIZE OF CABLE

SELECT JAWS

SWAGE TAPER



Failure and Remedies

- Batch size one plus learning curve
  - The first one has to work
  - If it doesn't, you can't keep trying until it works because it kills the business case
- Attempted fix:
  - Redesign so that swage is done before commitment
  - Insert selected jaws after swaging
  - Company rejected this: if the charge ignites, it might shoot the jaws out like bullets

Summary

- The influence of product architecture is pervasive
- It affects most aspects of product design and manufacturing
  - Product family design
  - Product structure including outsourcing and main subassemblies
  - Fulfillment, including customization and rapid response
- The outcomes of architecture decisions are implemented during assembly