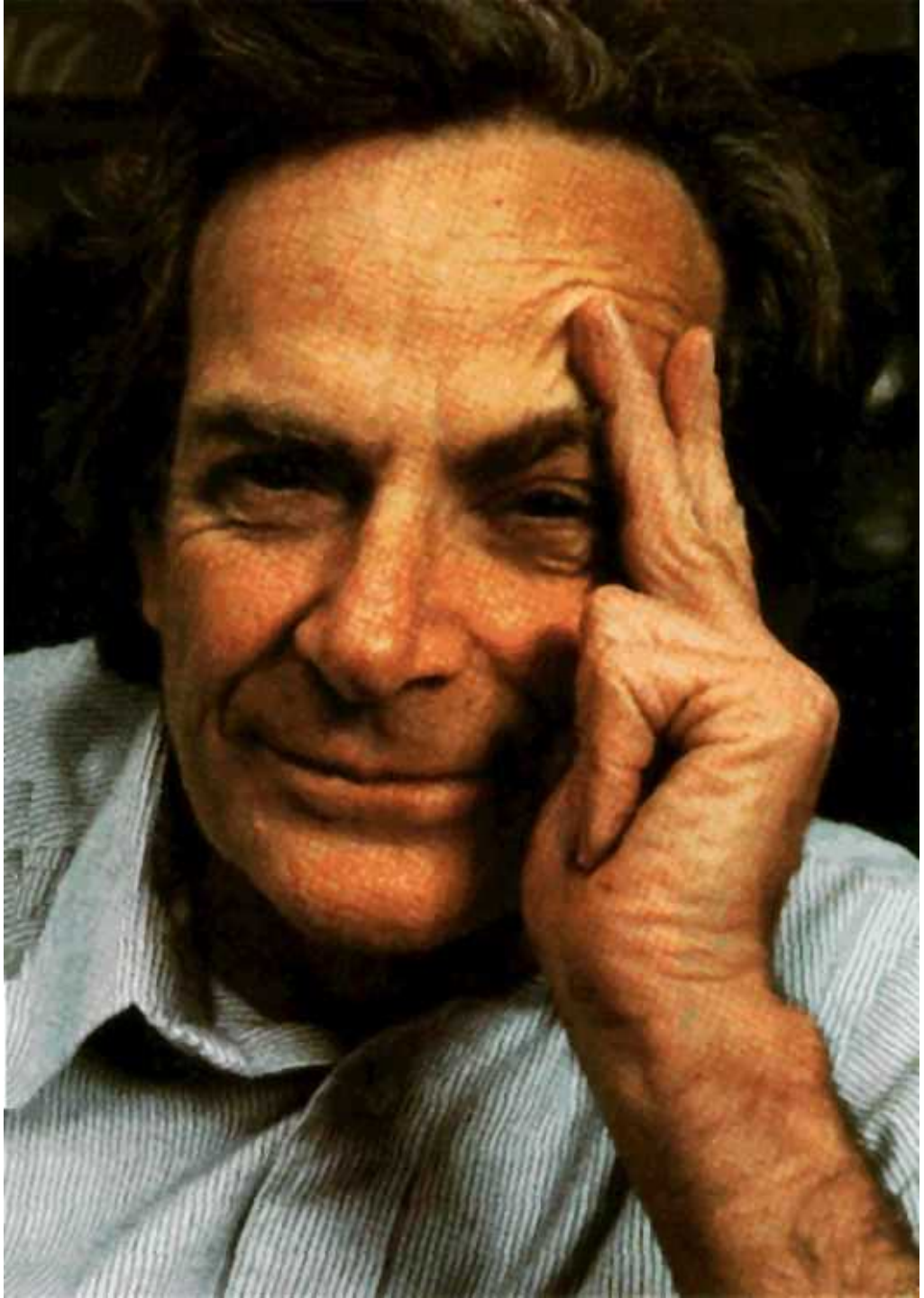
Transforming System Engineering from a Cargo-cult to a Rigorous Evidence-based Profession: Empirical Research into the Foundations of ISO 15288 and ISO 26702

Philippine Sea
Central Basin Trough
Kyushu-Palau Ridge
West Mariana Basin
Mariana Islands
Saipan
Guam
Mariana Trench
Northern Mariana Islands
Mid-Pacific Mountains
Wake Island
Micronesia
Hess Tablemount
Hawaiian Ridge
Hawai'ian Islands
Kaua'i
O'ahu
Moloka'i
Maui
Hawai'i
Mauna Kea 4205m
Hawaiian Trough
Molokai Fracture Zone
Tropic of Capricorn
Johnston Atoll
Philippine Basin
Yap
Challenger Deep -11,034m
East Mariana Basin
Melanesian Basin
Bikini Atoll
Enewetak
Marshall Seamounts
Marshall Islands
Vityaz Seamount
Christmas Ridge
Clarion Fracture Zone
Benham Seamount
Babeldaob
Yap Trench
Caroline Islands
Caroline Ridge
Magellan Seamounts
Chuuk
Pohnpei
Kosrae
Ralik Chain
Ratak Chain
Magellan Rise
Central Pacific Basin
Kingman Reef
Palmyra Atoll
Teraina
Tabuarean
Mindanao
Palau
Melanesia
Eauripik Rise
West Caroline Basin
East Caroline Basin
Ontong Java Rise
Tungaru (Gilbert Islands)
Baker & Howland Islands
Line Islands
Moluccas
New Guinea Trench
Admiralty Islands
Bismarck Archipelago
Bismarck Sea
New Ireland
New Britain
Nauru
Banaba
Tarawa
Kiritimati
Clipperton Fracture Zone
Nova Trough
Jarvis Island
Kanton
Enderbury Island
Phoenix Islands
Ceram Trough
Ceram
Sepik
New Guinea
Mount Wilhelm 4509m
Kikori
Fly
New Britain Trench
Bougainville Island
Solomon Islands
Solomon Sea
New Georgia Islands
Tungaru
Tuvalu
Weber Basin
Banda Sea
Kepulauan Aru
Arafura Sea
Torres Strait
Papua Plateau
Louisiade Archipelago
Osprey Reef
South Solomon Trench
Santa Cruz Islands
Vityaz Trench
Tokelau
Malden Island
Starbuck Island
Equator
Marquesas Islands
Galapagos Fracture Zone
Timor Trough
Arafura Shelf
Timor Sea
Joseph Bonaparte Gulf
Arnhem Land
Gulf of Carpentaria
Cape York Peninsula
Great Barrier Reef
Queensland Plateau
Coral Sea Basin
Coral Sea
Coral Sea Islands
PACIFIC PLATE
FIJI PLATE
Pandora Bank
Hazel Holme Bank
Robbie Ridge
Rotuma
Horizon Bank
Wallis and Futuna
Northern Cook Islands
American Samoa
Penrhyn
Manihiki Plateau
Vostok Island
Millennium Island
Marquesas Islands
Mururoa
Nuku Hiva
Hiva Oa
Banks Islands
Espiritu Santo
North New Hebrides Trench
Vanuatu
North Fiji Basin
Vanua Levu
Zephyr Reef
Savai'i
Samoa
Upolu
Tutuila
Manihiki
Samoa Basin
Cook Islands
Penrhyn Basin
Flint Island
Kimberley Plateau
Barkly Tableland
Tanami Desert
Great Sandy Desert
Iles Chesterfield
Efate
Erromango
Tanna
Iles Loyaute
Viti Levu
Lau Group
Fiji
Lau Basin
Tonga Trench
Niue
Bora-Bora
Rangiroa
Tuamotu Ridge
Tuamotu Islands
Society Islands
Raiatea
Tahiti
Hao
Tiki Basin
Great Dividing Range
New Caledonia
New Hebrides Trench
Tonga
Southern Cook Islands
Macdonnell Ranges
Simpson Desert
Lord Howe Seamounts
New Caledonia Basin
Norfolk Ridge
Cook Fracture Zone
South Fiji Basin
Horizon Deep
Rarotonga
Mauke
Cape Byron
Ozbourn Seamount
Kermadec Islands
French Polynesia
AUSTRALIA
Gibson Desert
Uluru (Ayers Rock) 867m
Lake Eyre North
Lake Torrens
Lake Everard
Lake Gairdner
Great Victoria Desert
Nullarbor Plain
Great Australian Bight
Flinders Ranges
Grey Range
Darling
Murray
Lachlan
Barwon
Lord Howe Island
Balls Pyramid
Norfolk Island
Three Kings Rise
Kermadec Ridge
Kermadec Trench
Louisville Ridge
Polynesia
Iles Australes
Rapa
Iles Gambier
Tropic of Capricorn
Pitcarn Island
Tasman Plain
Lord Howe Rise
West Norfolk Ridge
Northland Plateau
Bay of Plenty
Raukumara Plain
Southwest Pacific Basin
Kangaroo Island
Australian Alps
Mount Kosciuszko 2228m
Gascoyne Tablemount
North Island
Challenger Plateau
Tasman Sea
King Island
Bass Strait
Furneaux Group
South Island
Cook Strait
New Zealand
Aoraki (Mt Cook) 3744m
Southern Alps
Chatham Rise
Tasmania
East Tasman Plateau
Valerie

CALTECH



Is System Engineering a Cargo-cult Science?

System engineering is a standards-driven profession

- **ISO/IEC 15288 (2008); *Systems and Software Engineering—System Life Cycle Processes***
- **ISO/IEC TR 24748-1 (2010); *Systems and Software Engineering—System Life Cycle Processes: Part 1: Guide for life cycle management***

- **ISO/IEC DTR 16337 (?); *Systems Engineering—Systems Engineering Handbook***

- **ISO 26702 (2007); *IEEE Standard for Application and Management of the Systems Engineering Process***

- **ISO 24748-4 (?); *Systems Engineering—Application and Management of the Systems Engineering Process***

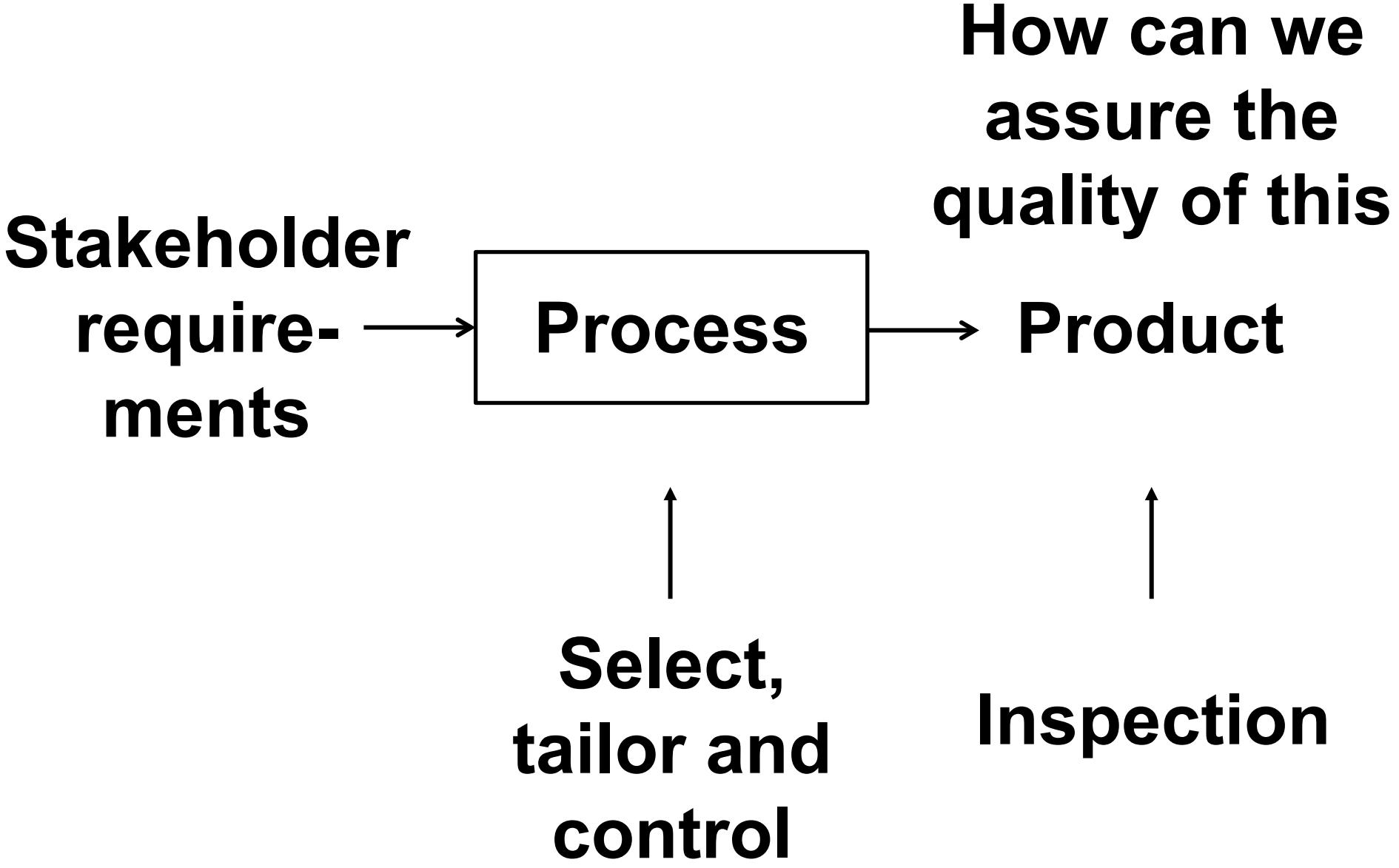
ISO/IEC 15288 (2008) page vi:

“There is therefore a need for a common framework to improve communication and cooperation among the parties that create, utilize and manage modern systems in order that they can work in an integrated, coherent fashion.”

ISO 9000 (2005) p v:

“This standard has been developed to assist organizations to implement and operate effective quality management systems.”

Point of departure



The quality of the product is determined by the quality of the process used to generate that product

The problem of a proxy

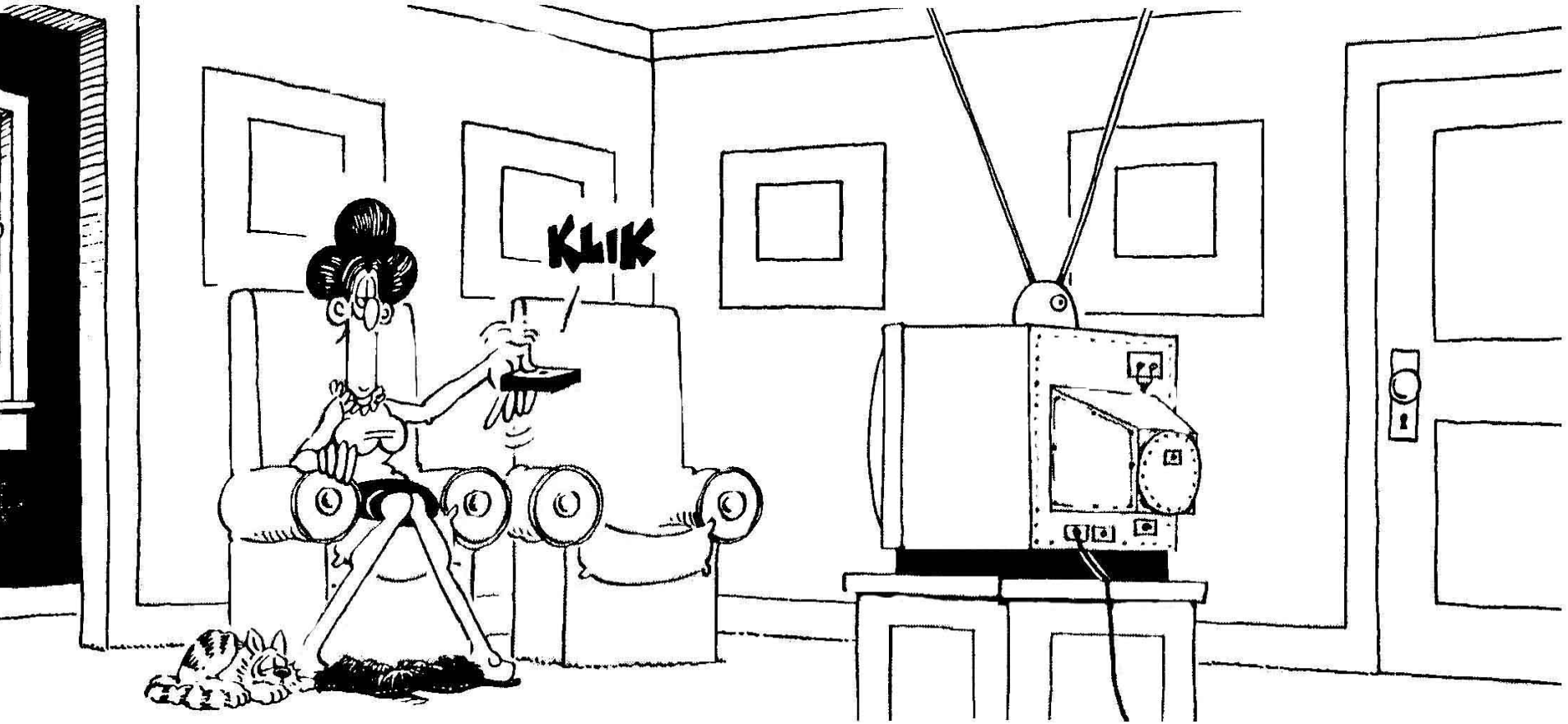
Rather than managing quality, merely comply to the best-practice processes defined in the standard

Best practices are based on a correlation of a quality outcome with system engineering processes

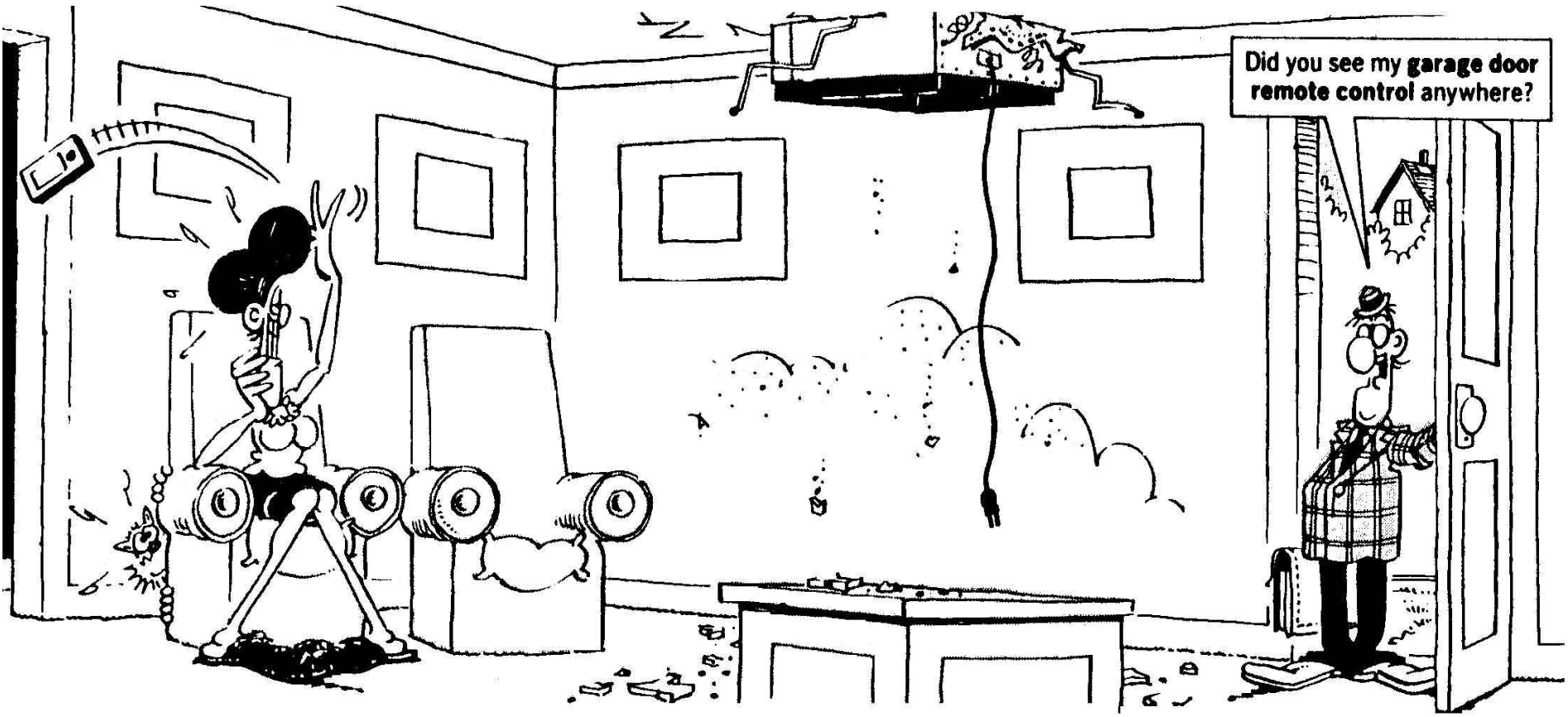
Correlation does not prove causation!

The “capability” of a process is the extent to which that process is explicitly defined, managed, measured and continuously improved

One Wednesday morning in Roxbury, Connecticut


KLIK

KAZASH


Did you see my garage door remote control anywhere?

Is system engineering a cargo-cult science?

The standard becomes the proxy for quality management

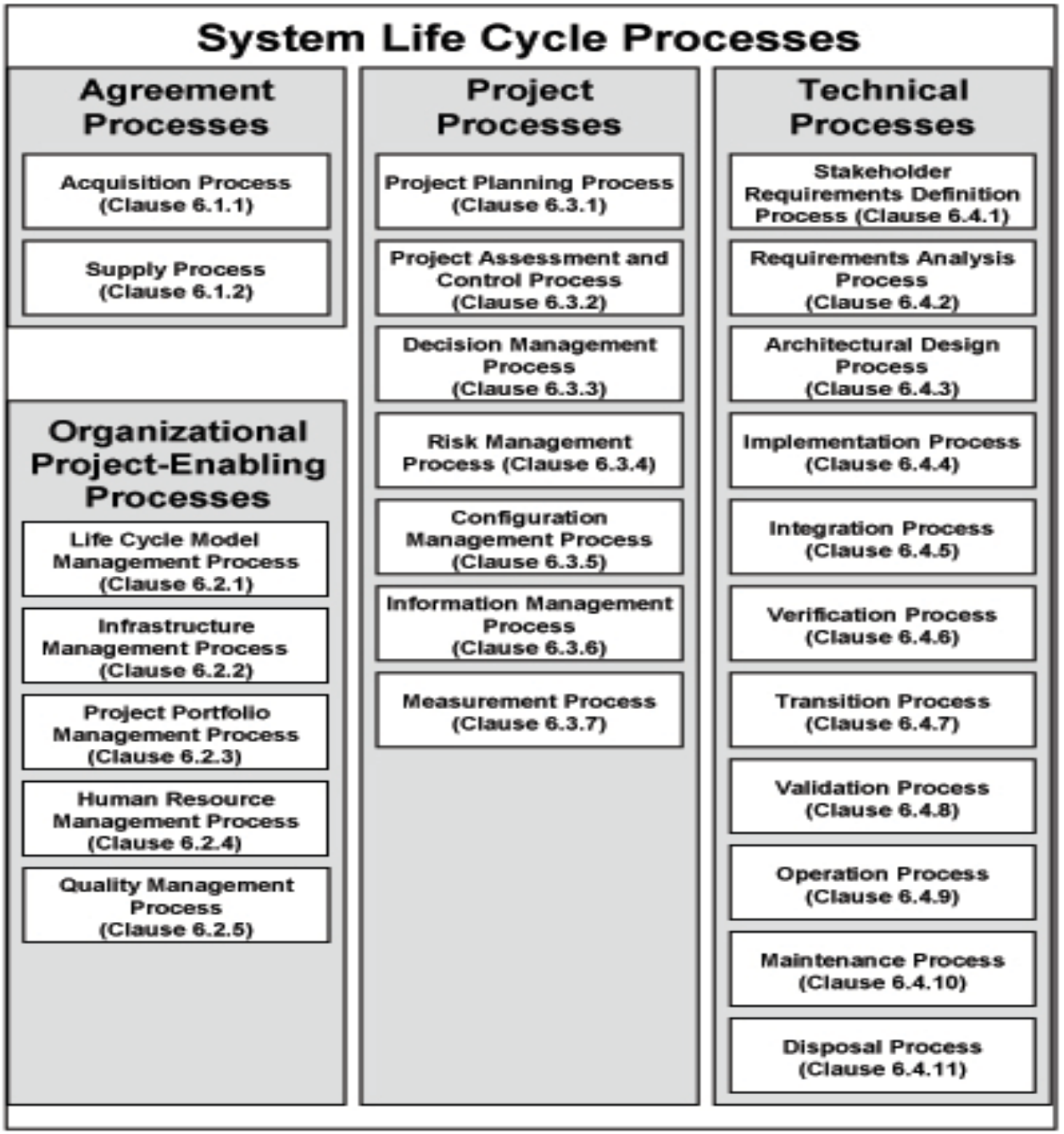
Merely copying successful behaviour does not in and of itself result in success

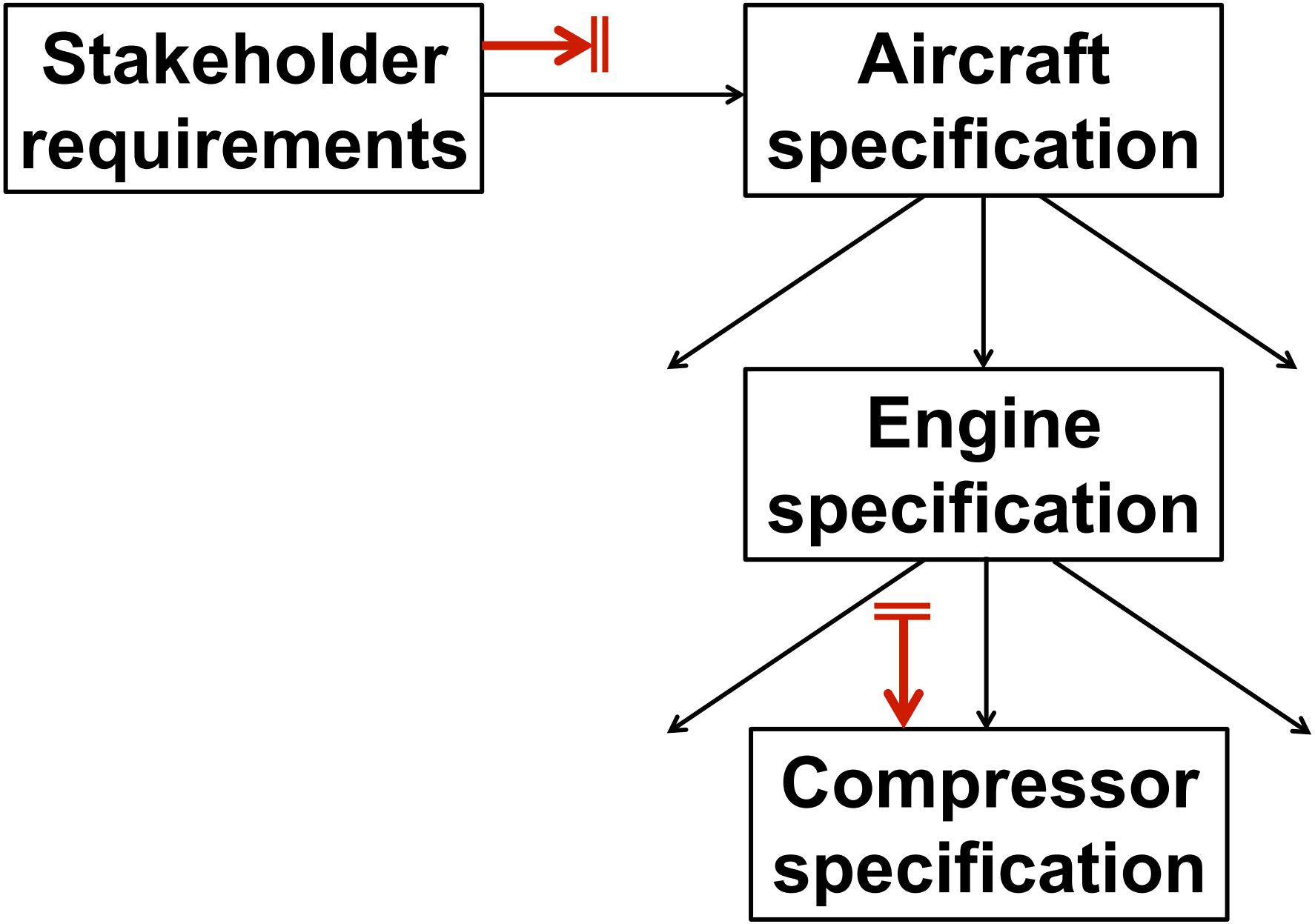
Is there any objective evidence obtained by empirical research that the system engineering processes defined in the standards result in improved quality?

Engineering is an applied science

System engineering is largely a social science

A social science is concerned with human behaviour in its social or cultural aspects


System Life Cycle Processes
Agreement Processes
Acquisition Process (Clause 6.1.1)
Supply Process (Clause 6.1.2)
Organizational Project-Enabling Processes
Life Cycle Model Management Process (Clause 6.2.1)
Infrastructure Management Process (Clause 6.2.2)
Project Portfolio Management Process (Clause 6.2.3)
Human Resource Management Process (Clause 6.2.4)
Quality Management Process (Clause 6.2.5)
Project Processes
Project Planning Process (Clause 6.3.1)
Project Assessment and Control Process (Clause 6.3.2)
Decision Management Process (Clause 6.3.3)
Risk Management Process (Clause 6.3.4)
Configuration Management Process (Clause 6.3.5)
Information Management Process (Clause 6.3.6)
Measurement Process (Clause 6.3.7)
Technical Processes
Stakeholder Requirements Definition Process (Clause 6.4.1)
Requirements Analysis Process (Clause 6.4.2)
Architectural Design Process (Clause 6.4.3)
Implementation Process (Clause 6.4.4)
Integration Process (Clause 6.4.5)
Verification Process (Clause 6.4.6)
Transition Process (Clause 6.4.7)
Validation Process (Clause 6.4.8)
Operation Process (Clause 6.4.9)
Maintenance Process (Clause 6.4.10)
Disposal Process (Clause 6.4.11)


Stakeholder requirements
Aircraft specification
Engine specification
Compressor specification

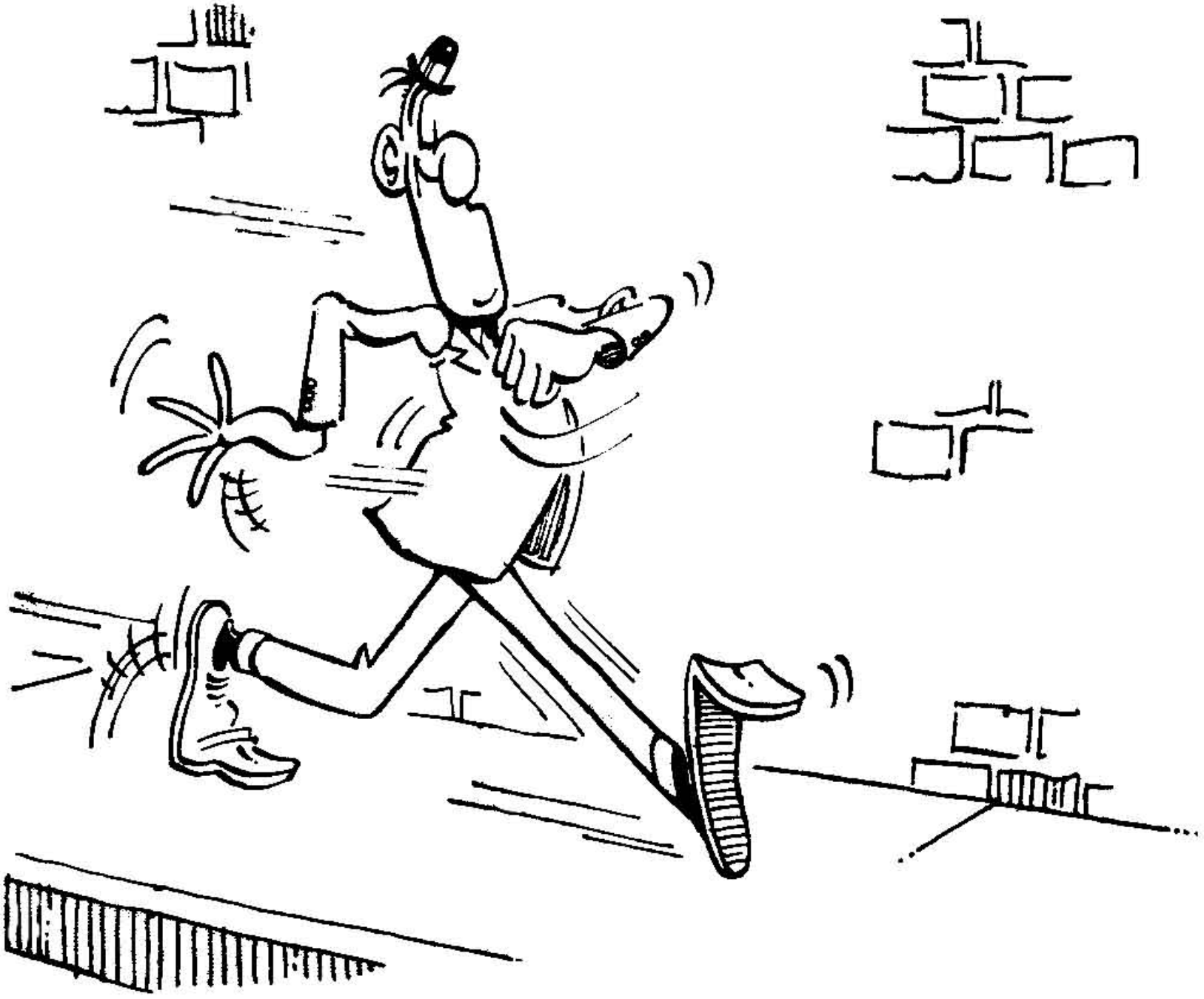
All orphan requirements are in principle suspect

All childless requirements are in principle suspect

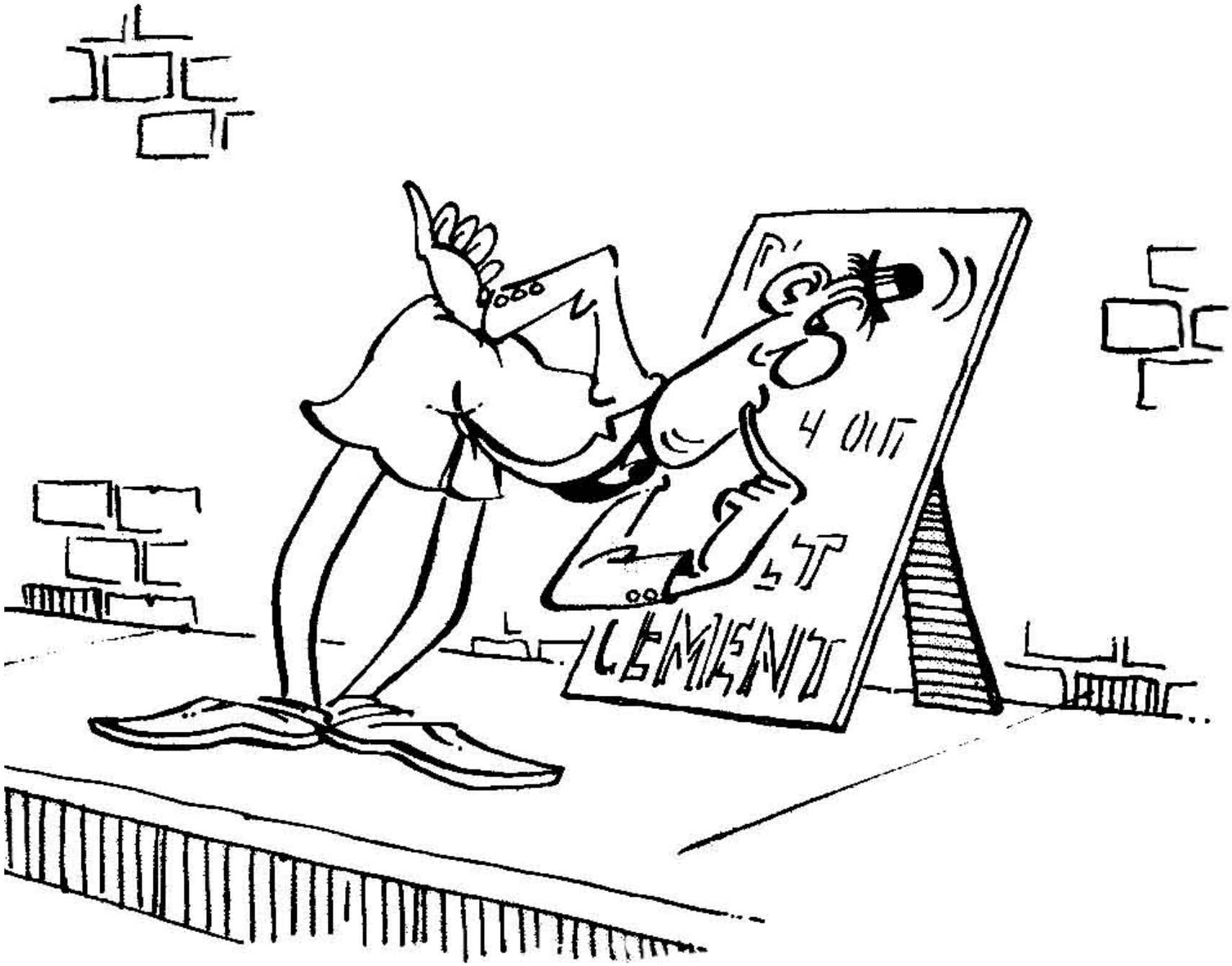
Research hypothesis

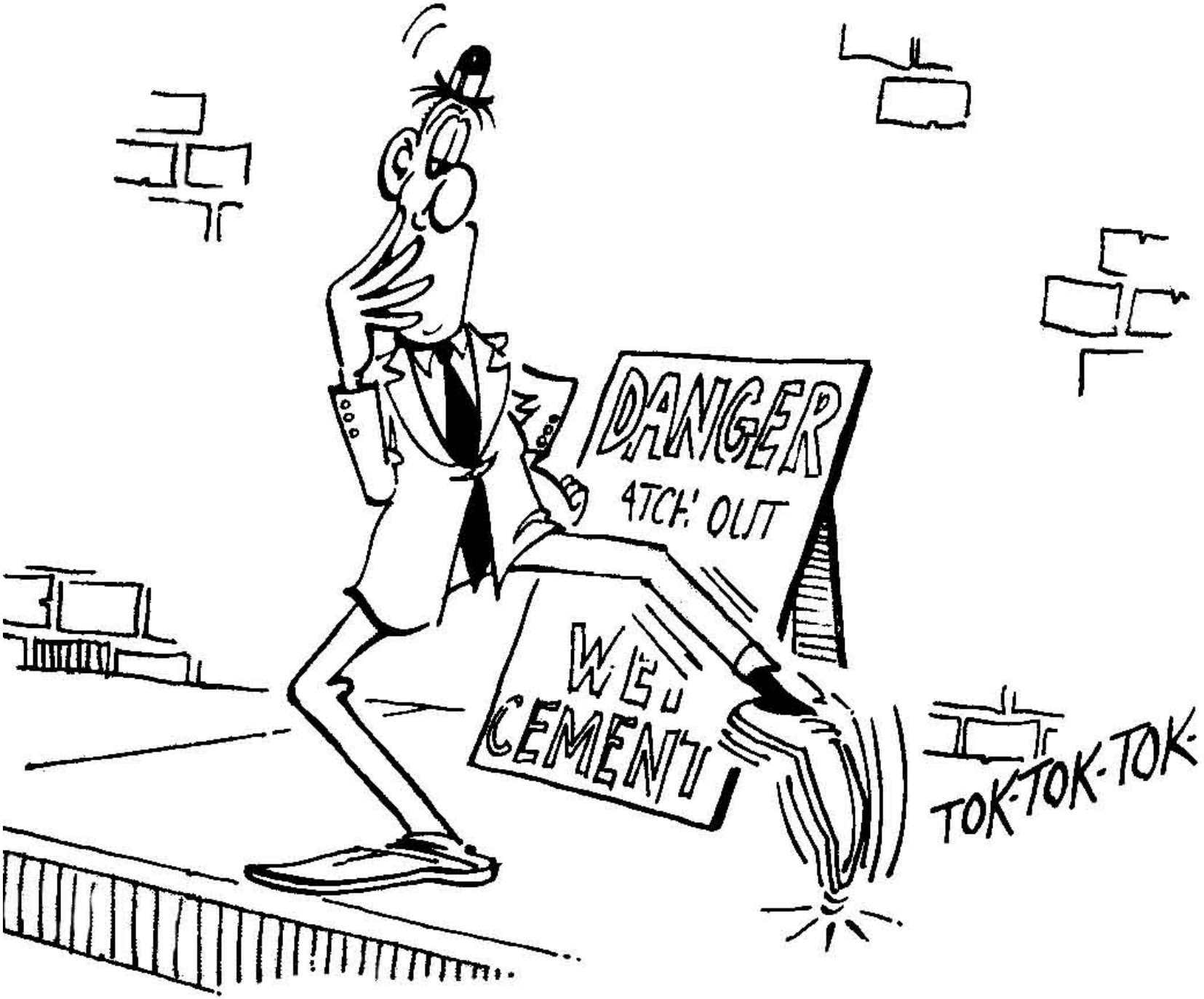
If a set of requirements satisfies the demands of bi-directional trace-ability, then the quality of the product that implements those requirements will be better than if bi-directional traceability had not been satisfied

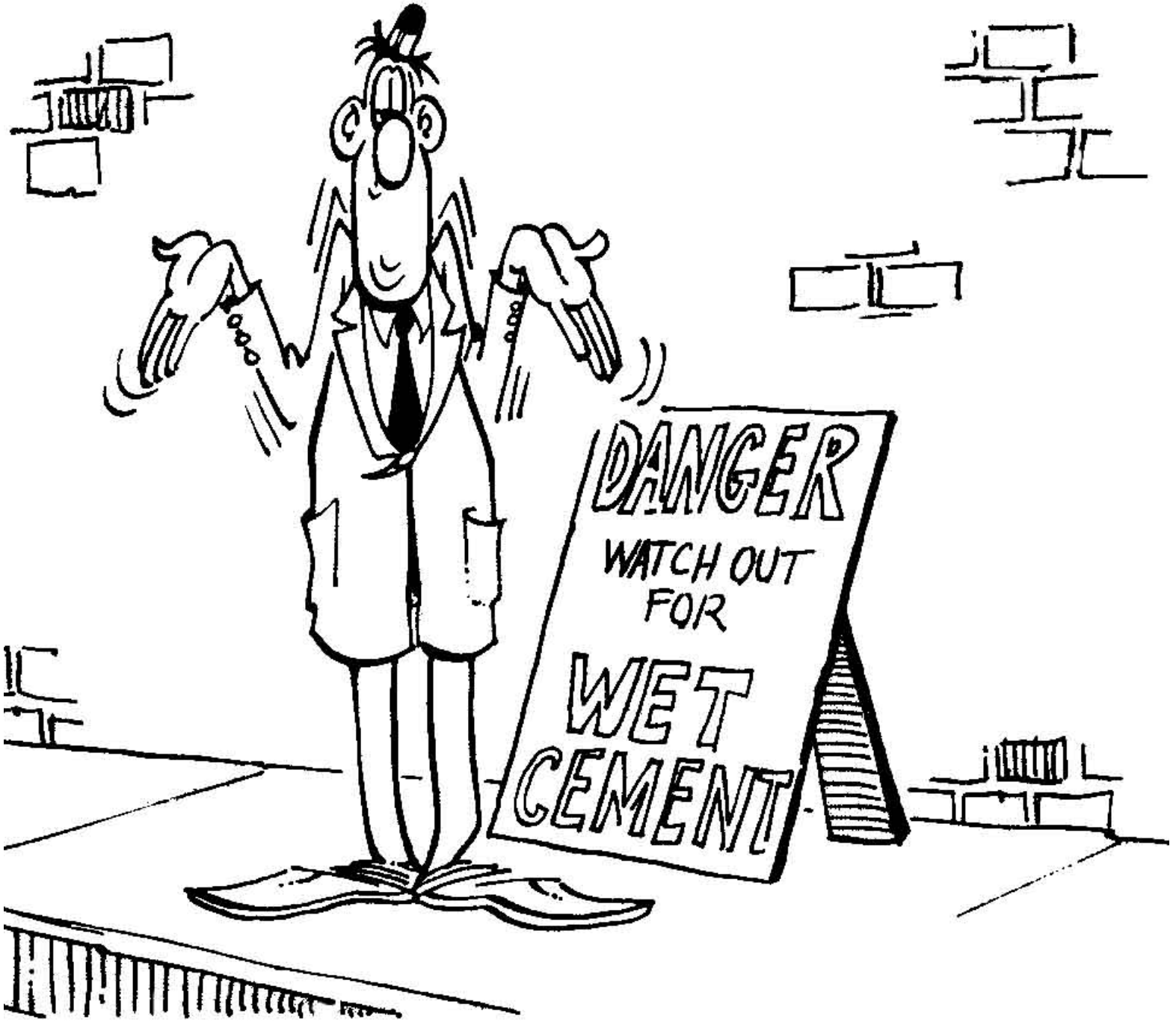
A QUICK STROLL



DANGER
WATCH OUT
FOR
WET
CEMENT
SKREEEK

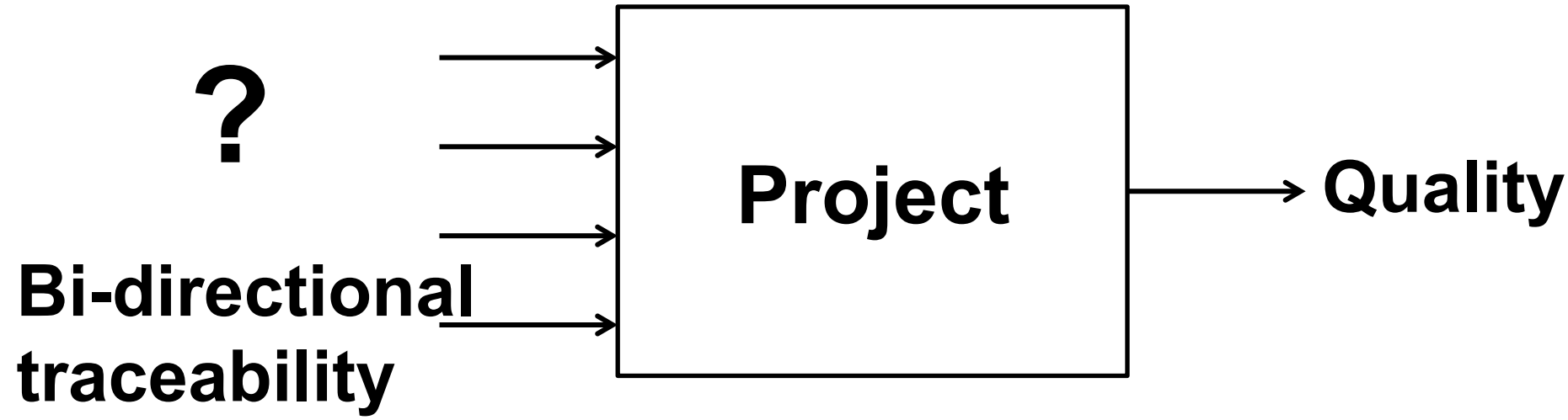

4 OIT
LT
CEMENT


DANGER
4TCH' OUT
WET
CEMENT
TOK-TOK-TOK-


DANGER
WATCH OUT
FOR
WET
CEMENT

BUILDING
UNDER
CONSTRUCTIO
KOONG
WES
CEM

Experiment to prove cause-and-effect relationship



Ex-post facto research design (“after the fact”)

An ex-post facto research design studies what has already happened. It luckily turns out that one project did use these techniques and another did not; both projects starting before the research study started

The most one can conclude from an ex-post facto research design is that an increase in product quality tends to be associated with the use of bi-directional traceability

Peter Checkland:

“If someone tells me ‘I have used your methodology and it works’, I will have to reply ‘How do you know that better results might not have been obtained by an ad hoc approach?’

If someone asserts ‘The methodology does not work’, I will reply, ungraciously but with logic, ‘How do you know the poor results were not due to your incompetence in using the methodology?’ ”

If system engineering aspires to the status of a scholarly discipline ‘it will have to show that within the subject there is a cycle of interaction between the formulation of theory relevant to serious problems or concerns, and the testing of that theory by methodology appropriate to the subject matter.

It will lead to ideas from which we can formulate two kinds of theory: *substantive* theories about the subject matter, … and *methodological* theories concerning how to go about investigating the subject matter.'

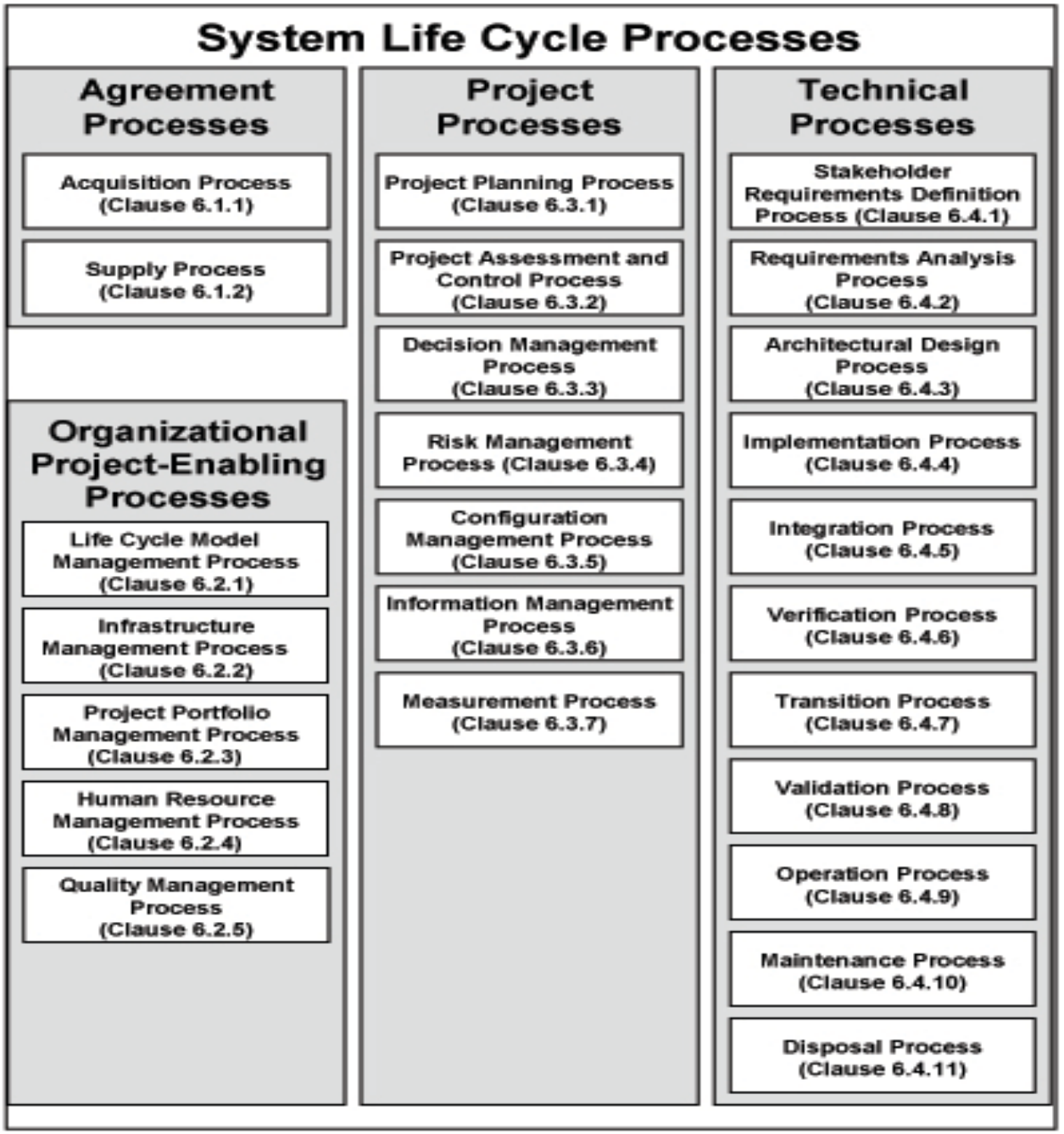
Peter Checkland

“Work on software development methodology must undergo a profound transformation. It should renounce its current reliance on fashion and political-style propaganda, turning instead to a serious scientific endeavour based on theory and experimental validation.

… As in politics—more accurately, bad politics—the emphasis currently is not on substantial solutions to hard problems, but on slogans, propaganda, and emotions.

Ideas are not presented through careful discussions of pros and cons, but marketed like brands; they are spread by gurus delivering the Holy Word. … These are signs of immaturity. The discipline needs to become adult."

The SEMAT (Software Engineering Method and Theory) initiative


System Life Cycle Processes
Agreement Processes
Acquisition Process (Clause 6.1.1)
Supply Process (Clause 6.1.2)
Organizational Project-Enabling Processes
Life Cycle Model Management Process (Clause 6.2.1)
Infrastructure Management Process (Clause 6.2.2)
Project Portfolio Management Process (Clause 6.2.3)
Human Resource Management Process (Clause 6.2.4)
Quality Management Process (Clause 6.2.5)
Project Processes
Project Planning Process (Clause 6.3.1)
Project Assessment and Control Process (Clause 6.3.2)
Decision Management Process (Clause 6.3.3)
Risk Management Process (Clause 6.3.4)
Configuration Management Process (Clause 6.3.5)
Information Management Process (Clause 6.3.6)
Measurement Process (Clause 6.3.7)
Technical Processes
Stakeholder Requirements Definition Process (Clause 6.4.1)
Requirements Analysis Process (Clause 6.4.2)
Architectural Design Process (Clause 6.4.3)
Implementation Process (Clause 6.4.4)
Integration Process (Clause 6.4.5)
Verification Process (Clause 6.4.6)
Transition Process (Clause 6.4.7)
Validation Process (Clause 6.4.8)
Operation Process (Clause 6.4.9)
Maintenance Process (Clause 6.4.10)
Disposal Process (Clause 6.4.11)

Without leadership and with a dysfunctional culture, processes will not ensure product quality. In other words, system engineering processes are necessary, but certainly not sufficient. Should system engineering not be viewed as an enabling system, rather than merely as a set of processes?

Excellence awards are based on both business enablers as well as business results. Process Management is merely one of many business enablers:

Malcolm Baldrige National Quality Award: Maximum score 8½%

European Foundation Quality Model: Maximum score 14%

“The comfort with which ISO 15288 can be accepted in a context depends on cultural dimensions such as:

- **the manner in which instruction is given—command by specific action or command by intent;**
- **communication—specific and detailed or open and general;**

- the manner in which people normally work together—collegial or master/servant;
- the attitude to availability of information—shared or closely guarded;
- means of dealing with problems—apportioning blame or generating solutions.

These dimensions differ across national, ethnic and industry contexts.”

Tim Ferris, 2006

Case study research will have to be used to uncover system engineering insights, and develop or test new principles

System engineering will be a fertile ground for many M.Sc. and Ph.D. theses in the years to come!

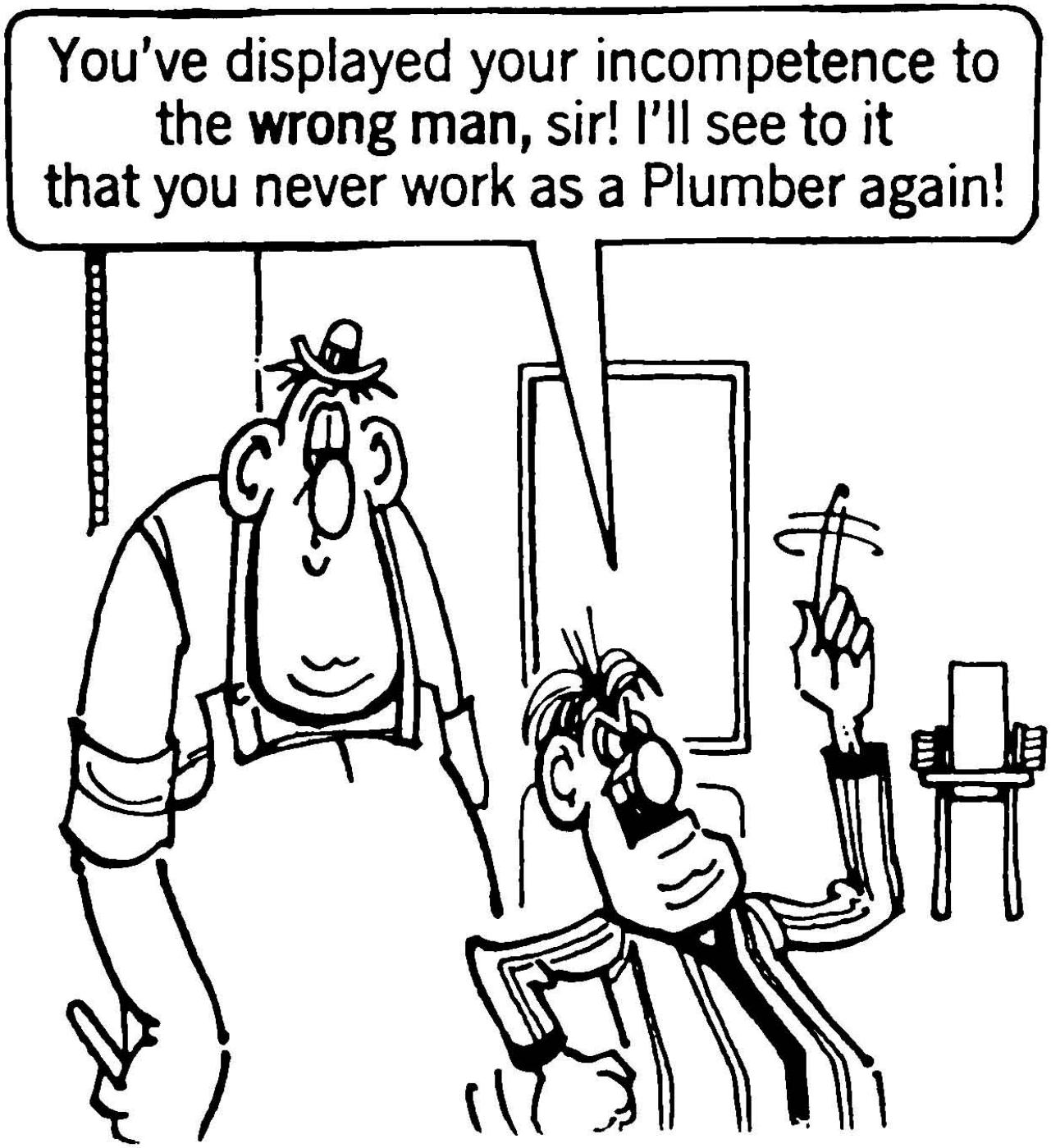
An early morning bathroom scene

And you call yourself a Plumber?!? You came in here just to fix a leaky pipe...and **now** look what you've done!!

I turn on the cold water...
and the **hot** water goes on!

I turn on the hot water... and the **toilet** flushes!
FVRSH
GLVRGLE
GLVG
GLVG
GLVG

I flush the toilet...
and the shower goes on!


You've displayed your incompetence to the **wrong man,** sir! I'll see to it that you never work as a Plumber again!

Hello, Operator? Get me
The Plumbers' Union...

SCHLIT

SPECIAL ARTICLE

The Quality of Health Care Delivered to Adults in the United States

Elizabeth A. McGlynn, Ph.D., Steven M. Asch, M.D., M.P.H., John Adams, Ph.D., Joan Keesey, B.A., Jennifer Hicks, M.P.H., Ph.D., Alison DeCristofaro, M.P.H., and Eve A. Kerr, M.D., M.P.H.

ABSTRACT

BACKGROUND

We have little systematic information about the extent to which standard processes involved in health care — a key element of quality — are delivered in the United States.

METHODS

We telephoned a random sample of adults living in 12 metropolitan areas in the United States and asked them about selected health care experiences. We also received written consent to copy their medical records for the most recent two-year period and used this information to evaluate performance on 439 indicators of quality of care for 30 acute and chronic conditions as well as preventive care. We then constructed aggregate scores.

RESULTS

Participants received 54.9 percent (95 percent confidence interval, 54.3 to 55.5) of recommended care. We found little difference among the proportion of recommended preventive care provided (54.9 percent), the proportion of recommended acute care provided (53.5 percent), and the proportion of recommended care provided for chronic conditions (56.1 percent). Among different medical functions, adherence to the processes involved in care ranged from 52.2 percent for screening to 58.5 percent for follow-up care. Quality varied substantially according to the particular medical condition, ranging from 78.7 percent of recommended care (95 percent confidence interval, 73.3 to 84.2) for senile cataract to 10.5 percent of recommended care (95 percent confidence interval, 6.8 to 14.6) for alcohol dependence.

CONCLUSIONS

The deficits we have identified in adherence to recommended processes for basic care pose serious threats to the health of the American public. Strategies to reduce these deficits in care are warranted.

From RAND, Santa Monica, Calif. (E.A.M., S.M.A., J.A., J.K., J.H., A.D.); the Veterans Affairs (VA) Greater Los Angeles Health Care System, Los Angeles (S.M.A.); the Department of Medicine, University of California Los Angeles, Los Angeles (S.M.A.); the VA Center for Practice Management and Outcomes Research, VA Ann Arbor Health Care System, Ann Arbor, Mich. (E.A.K.); and the Department of Medicine, University of Michigan, Ann Arbor (E.A.K.). Address reprint requests to Dr. McGlynn at RAND, 1700 Main St., P.O. Box 2138, Santa Monica, CA 90407, or at beth_mcglynn@rand.org.

N Engl J Med 2003;348:2635-45.
Copyright © 2003 Massachusetts Medical Society.

The New England Journal of Medicine
Downloaded from nejm.org on March 30, 2011. For personal use only. No other uses without permission.
Copyright © 2003 Massachusetts Medical Society. All rights reserved.

Percentage of recommended care received:

vaccinations.[43] About 38 percent of participants had been screened for colorectal cancer; annual fecal occult-blood tests could prevent about 9600 deaths annually.[43]

Nonresponse bias is a potential limitation of the study. Because the sample we analyzed included 37 percen… to be l… clear. … more l… eligible persons who did not participate in the study, our results may be biased toward an underestimation of deficits in quality related to underuse.

The… ical re… some … with d… has been examined in studies that compared process-based quality scores using standardized patients, vignettes, and abstraction of medical records[46] patient… the pre… ied we… medical records than with the use of vignettes and 10 percentage points lower with the use of medical records than with the use of standardized patients. About two thirds of the disagreement between data from standardized patients and data from audiotapes was attributable to reports by standardized patient… not co… ported… cal-rec… positiv… ement… might … higher… ing da… pant's … For ex… percen… fluenz… cent reported having received one. In general, the inclusion of self-reported data improved scores.

Our results indicate that, on average, Americans receive about half of recommended medical care processes. Although this point estimate of the size of the quality problem may continue to be debated, the gap between what we know works and what is

Table 5. Adherence to Quality Indicators, According to Condition.*

Condition	No. of Indicators	No. of Participants Eligible	Total No. of Times Indicator Eligibility Was Met	Percentage of Recommended Care Received (95% CI)
Prenatal care	39	134	2920	73.0 (69.5–76.6)
Low back pain	6	489	3391	68.5 (66.4–70.5)
Coronary artery	37	410	2083	68.0 (64.2–71.8)
Cerebrovascular disease	10	101	210	59.1 (49.7–68.4)
Chronic obstructive	20	169	1340	58.0 (51.7–64.4)
Osteoarthritis	3	598	648	57.3 (53.9–60.7)
Colorectal cancer	12	231	329	53.9 (47.5–60.4)
Asthma	25	260	2332	53.5 (50.0–57.0)
Benign prostatic hyperplasia	5	138	147	53.0 (43.6–62.5)
Hip fracture	9	110	167	22.8 (6.2–39.5)
Alcohol dependence	5	280	1036	10.5 (6.8–14.6)

* Condition-specific scores are not reported for management of pain due to cancer and its palliation, management of symptoms of menopause, hysterectomy, prostate cancer, and cesarean section, because fewer than 100 people were eligible for analysis of these categories. CI denotes confidence interval.

Diabetes mellitus **45.4% [42.7%; 48.3%]**

Colorectal cancer **53.9% [47.5%; 60.4%]**

Alcohol dependence **10.5% [6.8%; 14.6%]**

On average, Americans receive about half of the recommended medical care processes.

54.9% [54.3%; 55.5%]

The New England Journal of Medicine
Downloaded from nejm.org on March 30, 2011. For personal use only. No other uses without permission.
Copyright © 2003 Massachusetts Medical Society. All rights reserved.