

# **Business Dynamics: Systems Thinking and Modeling for a Complex World**

## **Errata**

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Please report additional errata to [BusDyn@mit.edu](mailto:BusDyn@mit.edu).

- The cedilla in Ceasescu should be under the first s, not the second c.
  - p. 6, line 5 (two instances)
  - p. 7, line 14
  - p. 951 (index) line 1
- p. 14, line 9: delete “to others”: The line should read “...and avoid describing the criticism you give or receive as feedback.”
- p. 26: Herbert Simon won the Nobel Memorial Prize in Economics in 1978, not 1979.
- In Section 2.2 the correct spelling is Zarrella, not Zarella. Correct the following instances:
  - p. 42, section 2.2, ¶ 2, line 3
  - p. 43, ¶ 2, line 1
  - p. 43, ¶ 5, line 1
  - p. 43, ¶ 5, line 2
  - p. 47, ¶ 4, line 1
  - p. 48, ¶ 5, line 6
  - p. 48, ¶ 5, line 8
  - p. 50, ¶ 2, line 3
  - p. 50, ¶ 3, line 1
  - p. 50, ¶ 4, line 1
  - p. 53, ¶ 1, line 1
  - p. 982 (index)
- p. 27, lines 12 and 13: the word “experience” is repeated in the sentence. The sentence should read:

“Further, the experiments show the misperceptions of feedback are robust to experience, financial incentives, and the presence of market institutions (see, e.g., Diehl and Sterman 1995; Paich and Sterman 1993; Kampmann and Sterman 1998).”
- p. 57 n: typo in the word “ultimately”. Change to “...the number of LHAs ultimately built...”

- p. 101, Figure 3-8 caption. Remove “Σ” in caption.
- p. 128, ¶ 2, first sentence: change to read “As a practical matter, one can never know...”
- p. 139, Table 5-1. In the “Mathematics” column, change “Y = ...” to “Y<sub>t</sub> = ...” in both instances (add the subscript t).
- p. 149, ¶ 2 line 1: Change “(section 5.1 provides...)” to “(section 5.4 provides...)”
- p. 201, section 6.2.3, ¶ 2, line 1. Replace “accounts payable” with “accounts receivable”.
- p. 234, line 9: change “6-second interval” to “ten second interval”:

“The approximation isn’t perfect because the net flow is actually changing during each ten-second interval.”

- p. 242, 2<sup>nd</sup> line from bottom: change to “assuming a significant fraction of carbon emissions simply disappears...”
- p. 267, line 11: The text is accurate if the state of the system is positive. Replace the final two sentences of the paragraph with the following, which apply in the general case:

“In general, the state of the system can be positive or negative, and the phase plot can be nonlinear. But wherever the slope of the phase plot is positive, the state of the system is governed by positive feedback: if the state is positive, it will get larger, leading to still greater increases; if it is negative, it will become even more negative. An equilibrium (where the rate of change of the state is zero) is unstable whenever the slope of the net rate at the equilibrium point is positive.”

- p. 269, note 6, line 5: change “p is the compounding period...” to “1/p is the compounding period...”
- p. 275, Figure 8-6. In the top panel, the polarity of the arrow from **d Fractional Decay Rate** to **Net Outflow Rate** should be positive.
- p. 277, Figure 8-9: missing “j” in Adjustment Time (all three parts of figure).
- p. 280, Figure 8-12. In the table of values at the bottom of the page, the value of  $1 - \exp(-2)$  is 0.86, not 0.87.
- p. 297, eq. 9-4 and 9-5: the leftmost integrals should read dP, not dp:

$$\int \frac{dP}{\left(1 - \frac{P}{C}\right)^P} = \int g^* dt \quad (9-4)$$

$$\int \frac{CdP}{(C-P)P} = \int \left[ \frac{1}{P} + \frac{1}{(C-P)} \right] dP = \int g^* dt \quad (9-5)$$

- p. 297, note 1: replace “infection point” with “inflection point”.
- p. 314, 9.2.6, line 4: While variants are used, the correct term and spelling is Creutzfeldt-Jakob Disease.
- p. 379, Figure 10-20. The polarity of the link from **Cost of Capital** to **Investments in Innovation, Quality, and Differentiation** should be negative.
- p. 420, first line after eq. 11-4: replace Material in Transit<sub>t</sub> with Material in Transit<sub>t(0)</sub>.
- p. 423ff: replace gw for gigawatt with GW.
- p. 433, eq. 11-9, last line: change from parentheses to curly brackets: (2,...,n) to {2,...,n}.
- p. 462, eq. 11-12: third term should read  $w_2 I_{t-2}$
- p. 465, eq. 11-26:  $\hat{D}$  should be squared in the equation and in the first line of p. 466:

$$\hat{n} = \text{INT} \left( \frac{\hat{D}^2}{s^2} \right)$$

“Of course, the ratio  $\hat{D}^2/s^2$  won’t in general be an integer, but rounding to the nearest integer generally introduces little error compared to the likely sampling errors in the data.”

- p. 477, eq. 12-8: change parentheses to curly brackets: (1,...,n-1) to {1,...,n-1}.
- p. 495 Challenge title: wrong font for ‘g D’ in “Training Delays”
- p. 544, 3<sup>rd</sup> line from bottom: change “give” to “gives”: “A useful formulation for resource allocation gives each...”
- p. 567, eq. 14-30. SPR in the last part of the equation should be SCR:

$$\dots = \text{SCR} * \text{DCR}/\text{SCR} = \text{DCR}$$

- p. 570, 2 lines after eq. 14-33: the values of the estimated coefficients are reversed. Replace text with:

“For the workweek, the estimated exponent (with 95% confidence bounds) is  $0.30 \leq s_{ww} = 0.36 \leq 0.43, R^2 = 0.70$ . The estimated exponent for time per task is  $-0.69 \leq s_{tpt} = -0.63 \leq -0.56, R^2 = 0.86$ .”

- p. 571, line immediately after eq. (14-34) should read:

“The estimated values give  $s_{ww} - s_{tpt} = 0.36 - (-0.63) \approx 1$ , which means”

- p. 633, Table 16-1: The correct source is Galbraith and Merrill 1996 (not 1992). Also correct in references, p. 932.
- p. 633, note 2: X and X\* are reversed in the second part of the note. The correct text is:

“Recall that in adaptive expectations the rate of change in the expectation  $X^*$  is given by  $dX^*/dt = (X - X^*)/D$  where X is the input variable and D is the time constant. Suppose X grows linearly at rate r units/time period. In the steady state  $X^*$  must also be growing linearly at rate r, requiring  $(X - X^*)/D = r$ , yielding a steady state error given by  $X - X^* = rD$ .

- p. 657, Eq. 16-17 should read:

$$\text{Normal Production} = \text{Capacity} * \text{Normal Capacity Utilization} \quad (16-17)$$

- p. 700, Figure 17-15 (Causal structure of real estate markets): Two causal links have the wrong sign.

The link from **Demand for Space** to **Vacancy Rate** should be negative.

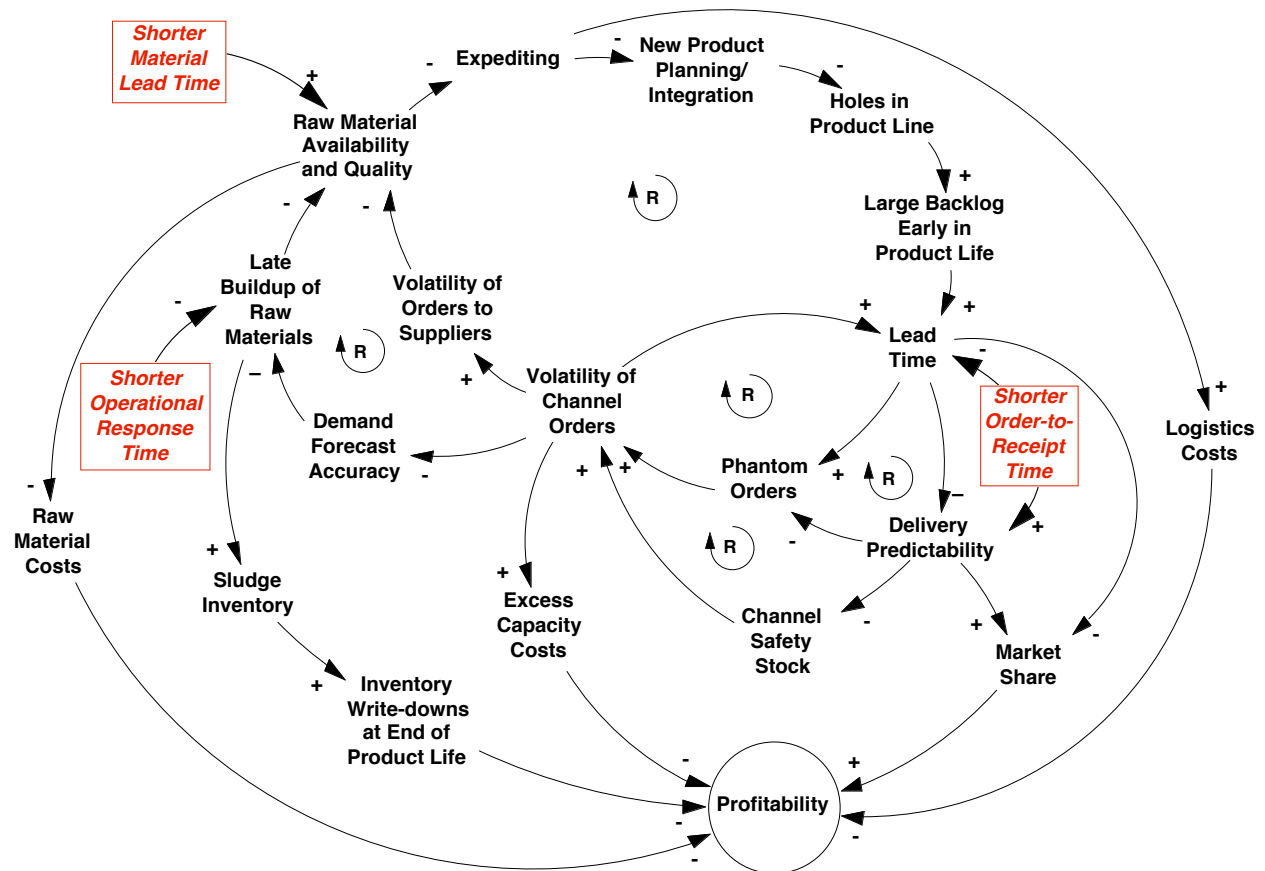
The link from **Buildings** to **Vacancy Rate** should be positive.

The polarities of the feedback loops indicated in the diagram are correct. The correct diagram is shown below.



- p. 752, Figure 18-22. The link from **Lead Time** to **Delivery Predictability** should have a negative polarity. The link from **Demand Forecast Accuracy** to **Late Buildup of Raw Materials** should have a negative polarity. The corrected figure is:

**Figure 18-22** Causal diagram showing sources of synergy among lead time reduction policies



Policies denoted by rectangles and italics.  
Source: Adapted from a McKinsey & Co. diagram.

- p. 801, Figure 20-8. The variable “Expected Markup” in Figure 20.8 is called “Expected Markup Ratio” in the model (see e.g. eq. 20-11 on p. 803).
- p. 818, final paragraph, line 6, change “The weaker the impact of price on costs,...” to “The weaker the impact of costs on price,...”
- P. 847 and 927: The citation to Bell and Senge (1980) should be Bell and Bell (1980). The full citation (p. 927) should read:

Bell, J. A. and J. F. Bell (1980) System Dynamics and Scientific Method, in Randers, J. (ed.) Elements of the System Dynamics Method. Waltham, MA: Pegasus Communications, 3-22.

- p. 874, note 13: The formula for the traditional  $R^2$  should be:

$$R^2 = 1 - \frac{\sum e^2}{\sum (X_d - \bar{X}_d)^2}$$

- p. 875, Table 21-5: The parentheses in the equations for  $U^M$  and  $U^S$  are misplaced. The correct equations are:

$$U^M = \frac{(\bar{X}_m - \bar{X}_d)^2}{MSE}$$

$$U^S = \frac{(s_m - s_d)^2}{MSE}$$

The correct table in its entirety is:

Metric	Definition	Formula
R <sup>2</sup>	Coefficient of determination; the fraction of the variance in the data “explained” by the model (dimensionless). r = correlation coefficient between model and data series	$R^2 = r^2; r = \frac{1}{n} \sum \frac{(X_d - \bar{X}_d)(X_m - \bar{X}_m)}{s_d s_m},$ $\bar{X} = \frac{1}{n} \sum X; s = \sqrt{\frac{1}{n} \sum (X - \bar{X})^2}$
MAE	Mean Absolute Error (units)	$MAE = \frac{1}{n} \sum  X_m - X_d $
MAPE	Mean Absolute Percent Error (dimensionless)	$MAPE = \frac{1}{n} \sum \frac{ X_m - X_d }{X_d}; \text{ (multiply by 100 for \%)}$
MAE/Mean	Mean Absolute Error as a fraction of the mean (dimensionless)	$MAE/Mean = MAE/\bar{X}_d; \text{ (multiply by 100 for \%)}$
(R)MSE	(Root) Mean Square Error (RMSE: units; MSE: units <sup>2</sup> )	$MSE = \frac{1}{n} \sum (X_m - X_d)^2; RMSE = \sqrt{MSE}$
Theil's Inequality Statistics	Decomposes MSE into three components: bias (U <sup>M</sup> ), unequal variation (U <sup>S</sup> ), and unequal covariation (U <sup>C</sup> ) (dimensionless); U <sup>M</sup> + U <sup>S</sup> + U <sup>C</sup> = 1	$U^M = \frac{(\bar{X}_m - \bar{X}_d)^2}{MSE}$ $U^S = \frac{(s_m - s_d)^2}{MSE}$ $U^C = \frac{2(1 - r) s_m s_d}{MSE}$

- p. 918, equation B-6 should read:

$$\text{White Noise} = \text{Mean} + \text{Standard Deviation} * (24 * \text{Correlation time}/dt - 12)^{0.5} * \text{UNIFORM}(-0.5, 0.5, \text{Noise Seed}) \quad (\text{B-6})$$

Note that the models on the disc that accompanies Business Dynamics in which pink noise is used need to be corrected per the correct equation above.

- p. 918, last paragraph, change “the highest frequency in any model variable is twice the time step dt...” to “the shortest periodicity possible in any model variable is twice the time step dt...”