Revised 5/10/04

An Analytical Model That Provides Insights into Various C2 Issues

James G. Taylor, Beny Neta

Naval Postgraduate School

Peter A. Shugart

USA TRADOC Analysis Center

The 2004 Command and Control Research and Technology Symposium

June 2004

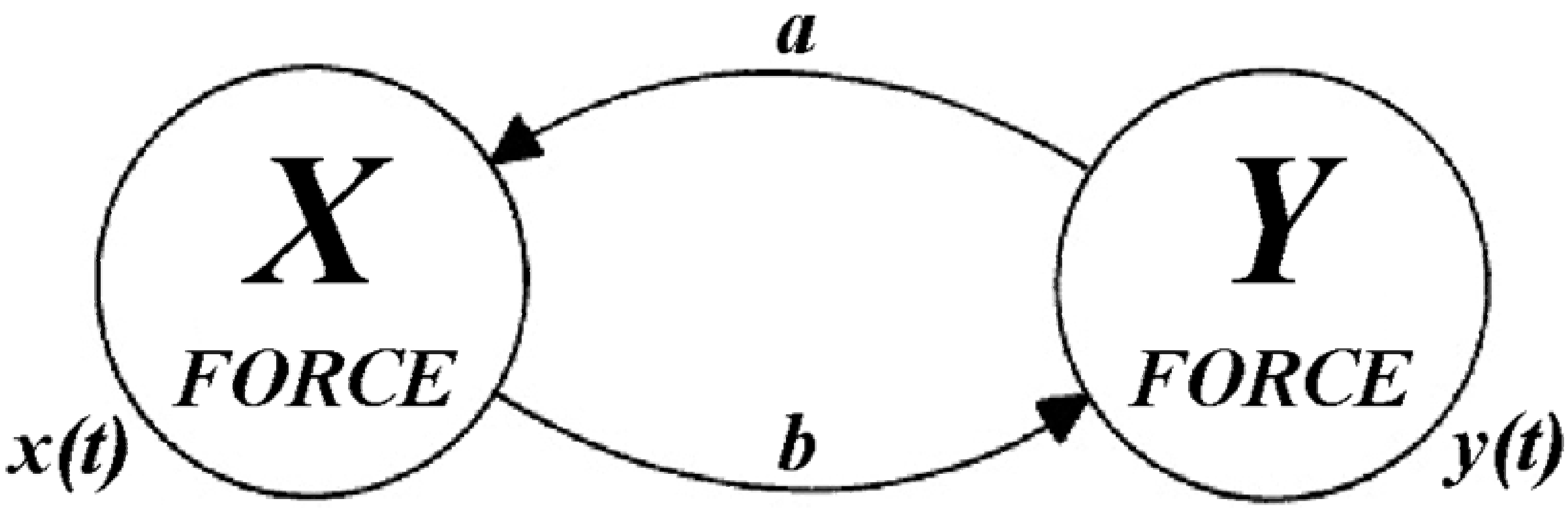
Overview

- ***Model of Parallel Acquisition of Targets***
  - ☞ ***Kill Rate Consequences***
    - ✓ ***Taylor's New General Methodology for Lanchester Attrition-Rate Coefficients***
    - ✓ ***Analytical Expression for Kill Rate***
      - ***Higher Kill Rate Than for Serial Acquisition***
- ***Insights into Network-Centric Warfare***

Effects of Parallel Acquisition

- ***More Efficient Target Acquisition***
- ***Force Multiplier***
  - ☞ ***Inflict More Casualties on Enemy***
  - ☞ ***Sustain Fewer Casualties***
- ***Example***
  - ☞ ***X Force Can Effect Change from Serial to Parallel Acquisition of Targets***

Basic Lanchester-Type Paradigm



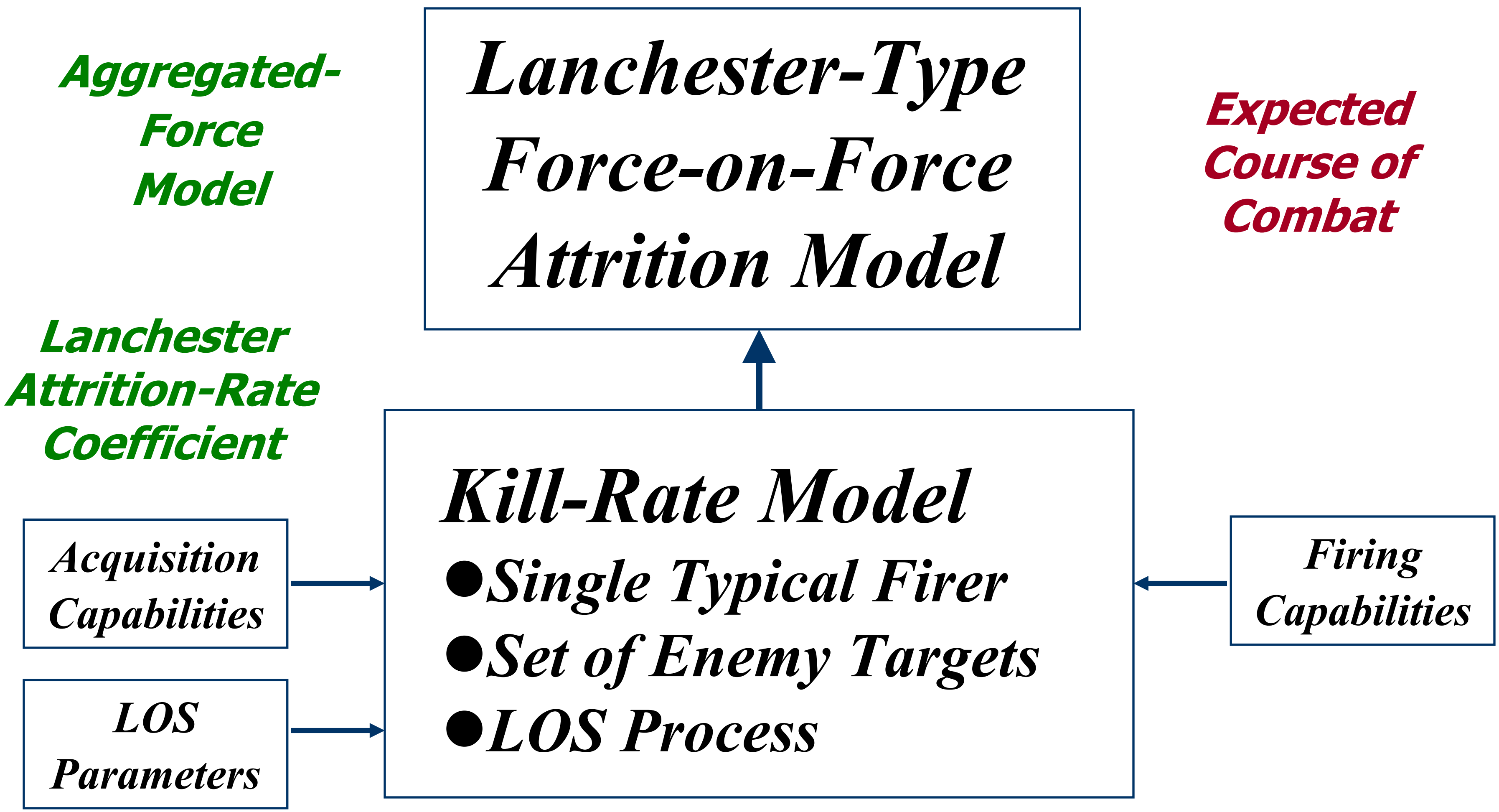
$$\begin{cases} \dfrac{dx}{dt} = -a\,y & \text{with } x(0) = x_0 \\[2ex] \dfrac{dy}{dt} = -b\,x & \text{with } y(0) = y_0 \end{cases}$$

Simplified Representation

Lanchester Attrition-Rate Coefficients

- ***a* and *b* are Called Lanchester Attrition-Rate Coefficients**
- ***a* = Rate at Which an Individual Y Firer Kills X Targets (Single-Weapon-System-Type Kill Rate); Kill Rate of Single Typical Firer**

Conceptual Combat Model



Kill-Rate Model

- ***Considers Single Typical Firer against Passive Target***
  - ☞ ***No Consideration of Duel***
- ***Does Not Consider Effect on Target by Any Other Firer***
  - ☞ ***Can Develop Correction Factor to Account for Such Effects***

New General Methodology
for Lanchester Attrition-Rate Coefficients

- ***Recently Developed by Taylor***
- ***Greatly Expands Modeling Capabilities***
  - ☞ ***Great Detail in Target-Engagement Cycle***
    - ✓ ***Special Treatment of First Round(s)***
    - ✓ ***Actual Distributions for Event (e.g. Interfiring) Times***
  - ☞ ***Battle Damage Assessment***
  - ☞ ***Command & Control at Platform Level***
  - ☞ ***Insights into Network-Centric Warfare***

Conditions Considered

- ***Heterogeneous-Target Environment***
- ***Stochastic Line of Sight (LOS)***
- ***Target-Acquisition Times Independent (But Otherwise Arbitrary)***
- ***Interfiring Times Independent (But Otherwise Arbitrary)***

New Methodology

- ***Kill Rate Computed as Ratio of***
  - ☞ ***Expected Number of Kills in Target-Engagement Cycle to***
  - ☞ ***Expected Duration of Target-Engagement Cycle***

$$a_{ij} = \frac{\bar{n}^{cycle}_{k_{X_i Y_j}}}{\bar{t}_{cycle_{Y_j}}}$$

Can Now Model

- ***In Tank Warfare***
  - ***First Round Chambered***
  - ***Tank Commander Acquires Targets While Gunner Engages***
  - ***Automatic Loader (in Russian Tanks)***
- ***Information Aspects***
  - ***Battle Damage Assessment***
    - ✓ ***Time to Assess***
  - ***False Targets***

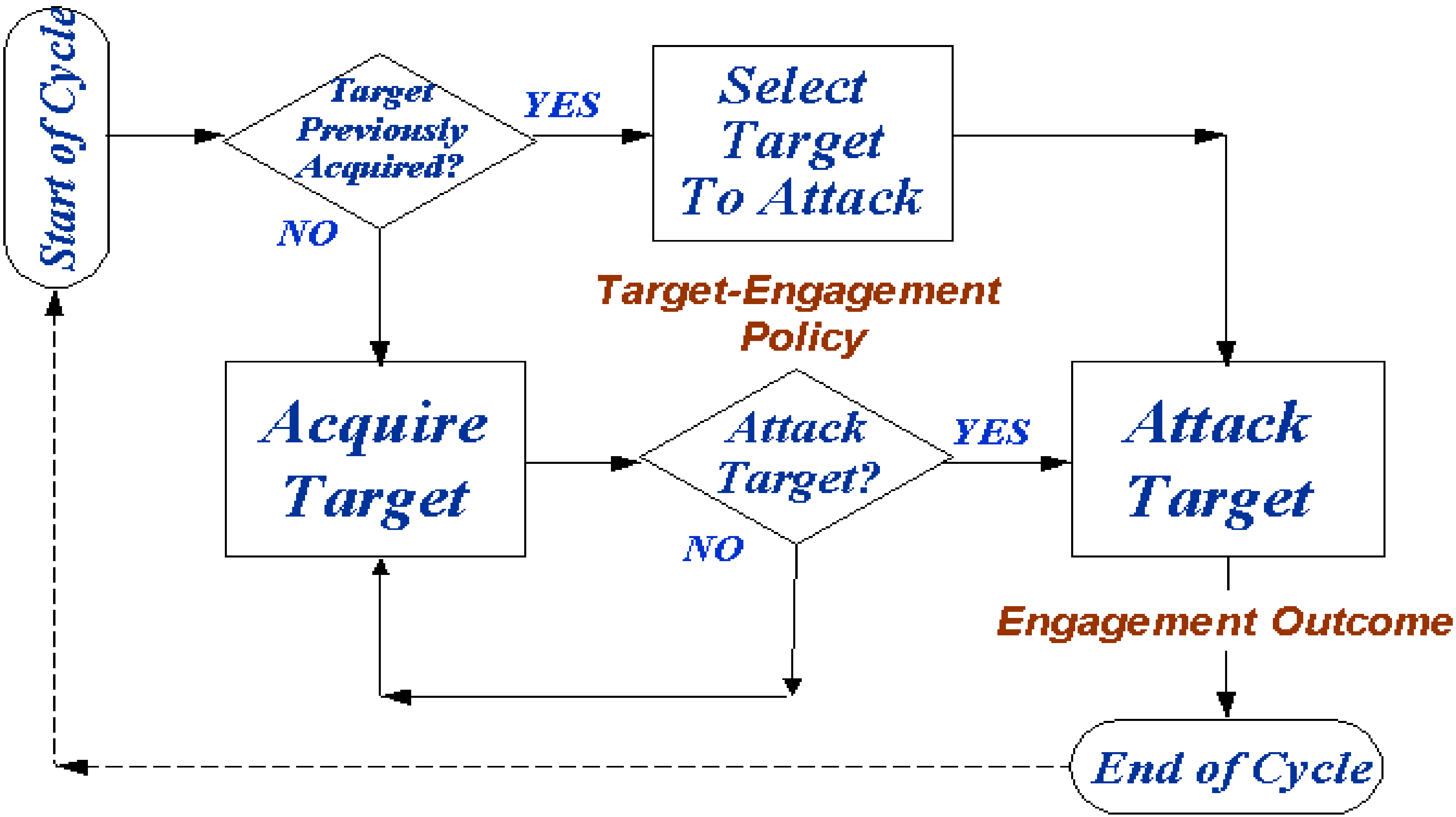
Conditions in Specific Cases

- ***Heterogeneous-Target Environment***
- ***Stochastic Line of Sight (LOS)***
- ***Target-Acquisition Times Exponential (and Independent)***
- ***Interfiring Times Exponential (and Independent)***
  - ☞ ***Can Be Extended to Log Normal/Erlang Times***

Key Question

- *Can New Targets Be Acquired While an Acquired Target Is Being Engaged?*
- *Simplest Model Considers Two Cases*
  - ☞ *No New Target Can Be Acquired*
    - ✓ *Serial Acquisition*
  - ☞ *New Target Can Be Acquired (At Same Rate)*
    - ✓ *Parallel Acquisition*

Target-Engagement Cycle
(Parallel Acquisition of Targets)

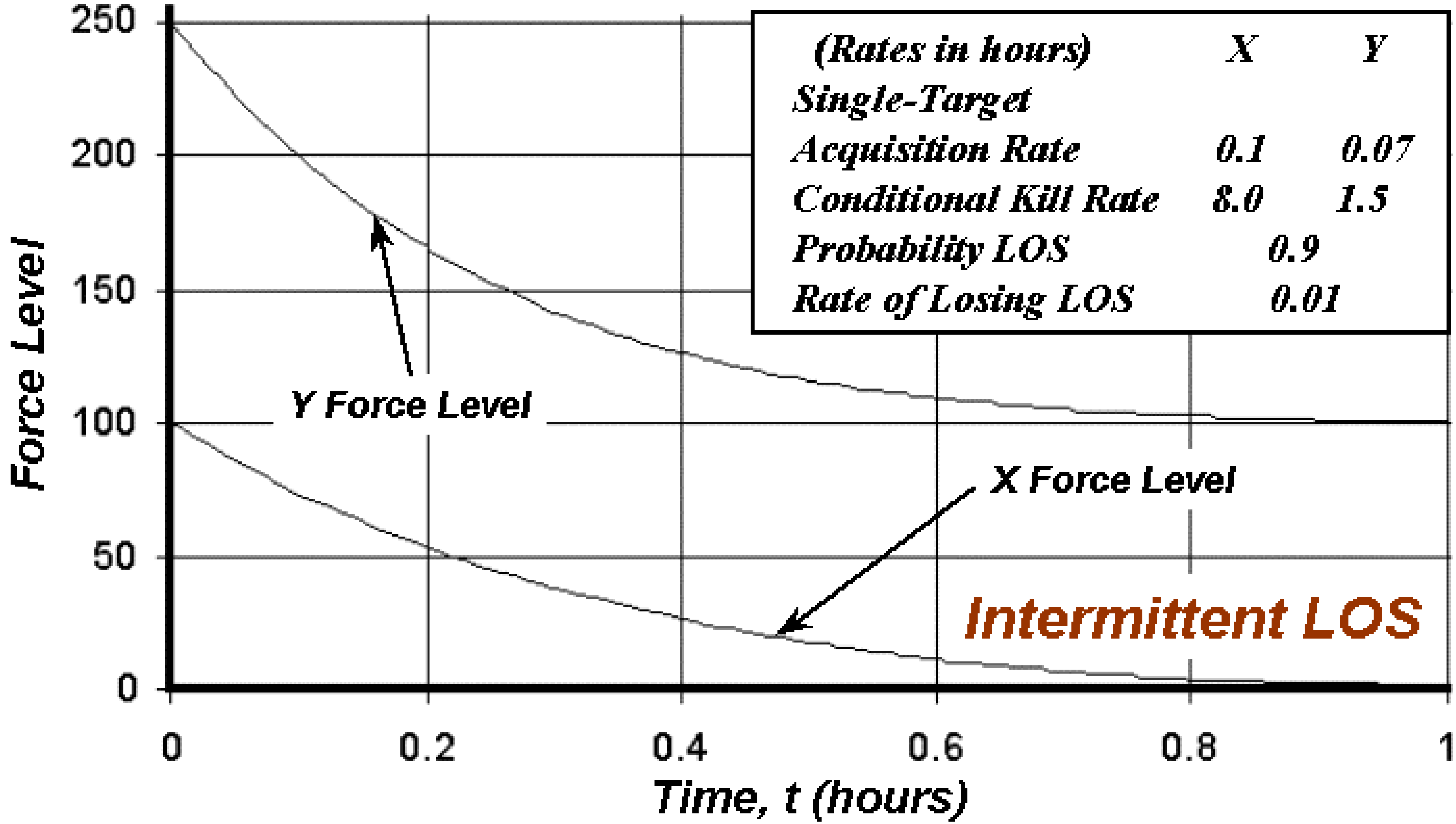


Some Computations

- ***Y Always Uses Serial Acquisition***
- ***X Can Change from Serial Acquisition of Enemy Targets to Parallel Acquisition***
  - ***Computations Done for These Two Cases***
    - ✓ ***Serial Acquisition by X***
    - ✓ ***Parallel Acquisition by X***

Both Sides Serial

(Force-Level Decays)



Combat Model

(Only X Force Uses Parallel Acquisition)

$$\left\{ \begin{aligned} \frac{dx}{dt} &= -\left\{ \frac{P_{K(LOS)_{XY}}\, y}{\dfrac{1}{P_{LOS}\, \lambda_{XY}\, x} + \dfrac{1}{(\alpha + \mu)}} \right\} \\ \frac{dy}{dt} &= -\left\{ \frac{P_{K(LOS)_{YX}}\, x}{\dfrac{\left(1 - B(t)\right)}{P_{LOS}\, \lambda_{YX}\, y} + \dfrac{1}{(\beta + \mu)}} \right\} \end{aligned} \right.$$

Intermittent LOS

Target Availability

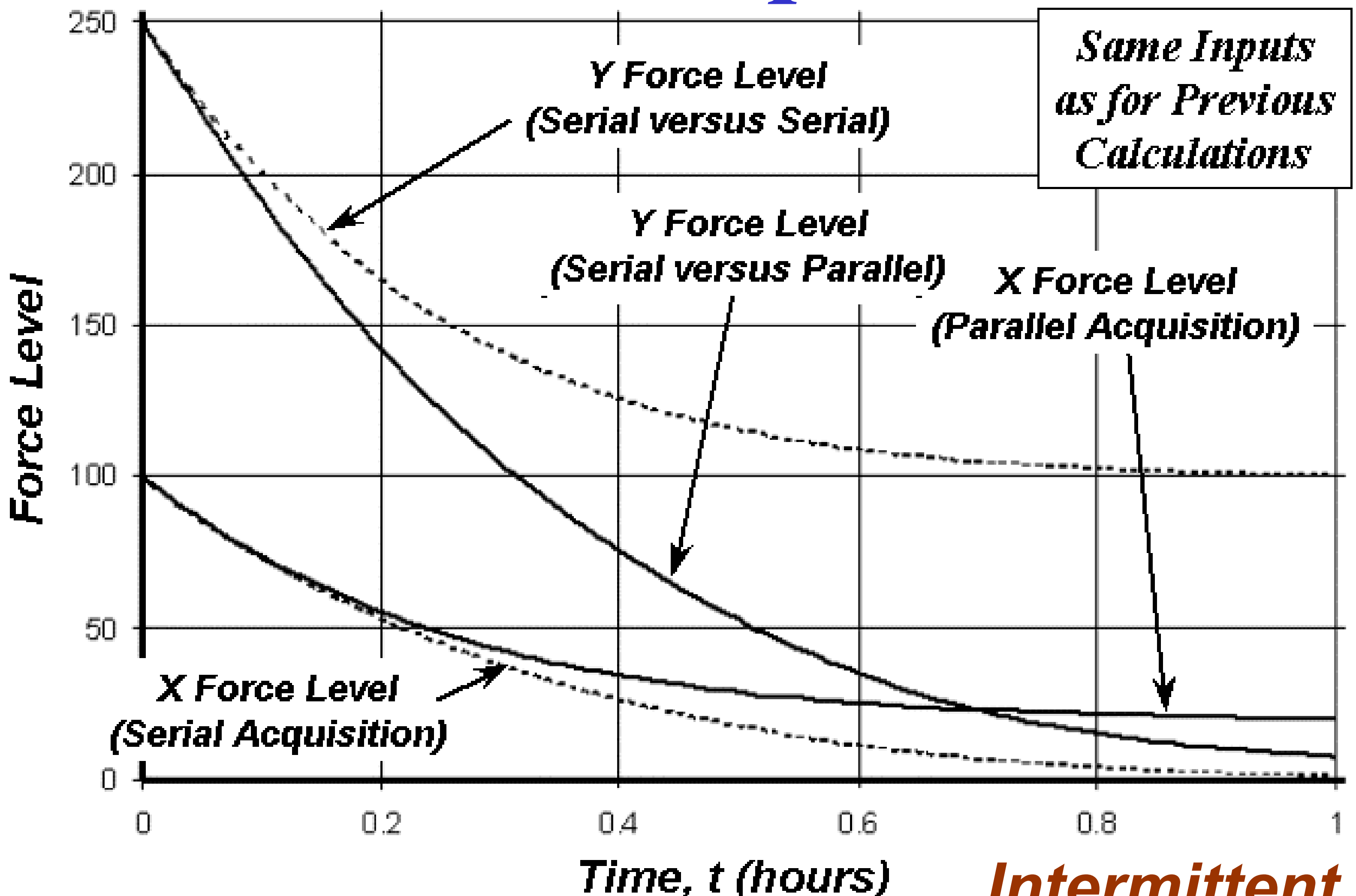
- **_Typical X Firer Keeps on Continuously Acquiring Targets from Beginning of Battle_**

Intermittent LOS

- **_Target Availability Given by (Assuming Steady State for LOS Process and No Targets Initially Acquired)_**

$$B(t) = P_{LOS}\left\{\frac{\lambda_{YX}}{\lambda_{YX}+\mu}\right\}\left\{1 - e^{-(\lambda_{YX}+\mu)t}\right\}$$

Effects of Changing from Serial to Parallel Acquisition



Intermittent LOS

Benefits to X

- ***Inflicts 62% More Attrition***
- ***Suffers 19% Less Attrition***
- ***Turns Defeat into Victory***

Final Comments

- ***Significant Benefits from Parallel Acquisition Demonstrated for Combat at Platform Level***
- ***Ideas Can Be Adapted to Modeling Network-Centric Warfare***
- ***Such Analytical Models Very Convenient for Showing Benefits from Network-Centric Warfare***