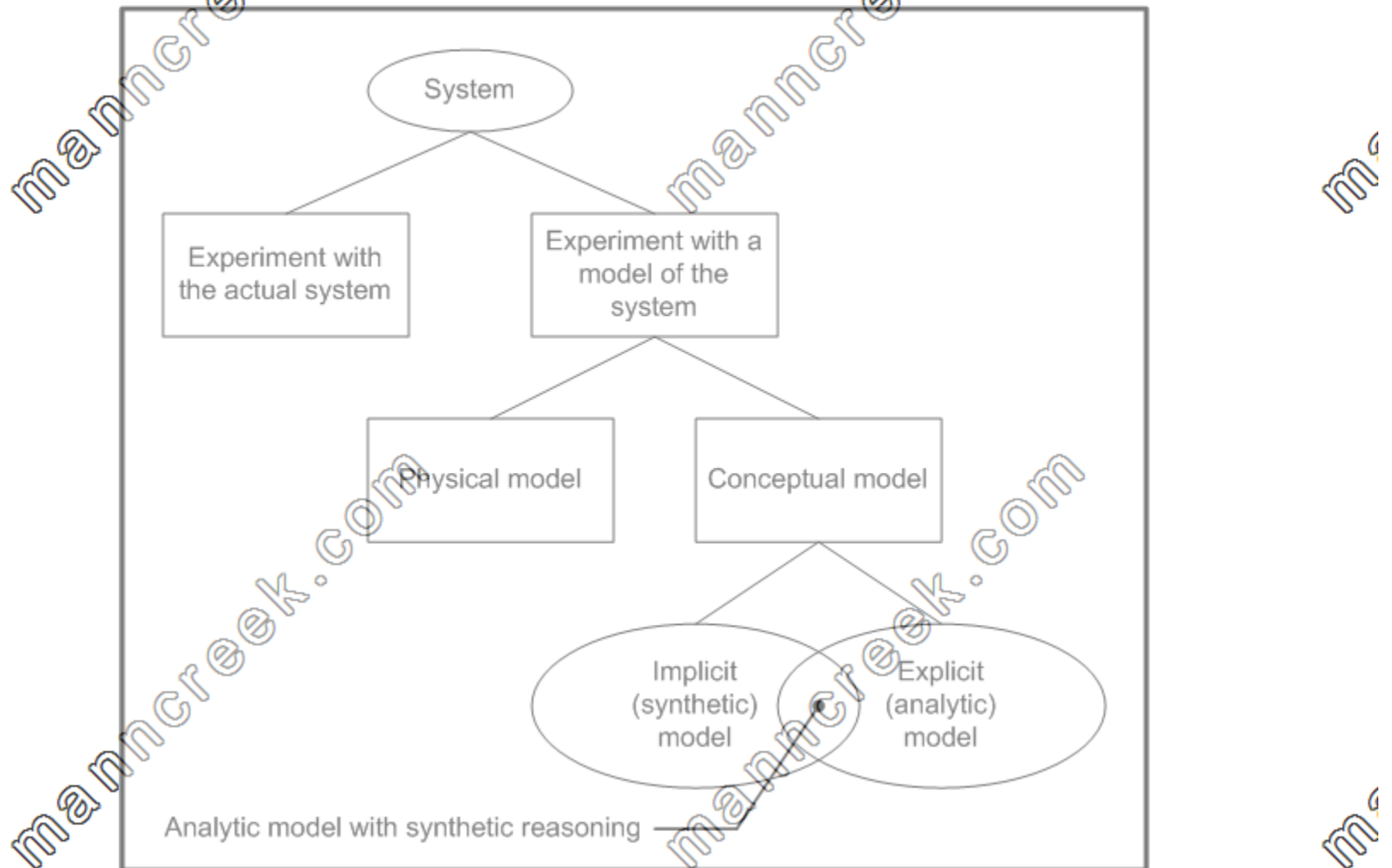


Notes on (Business) Systems Modeling and Simulation¹

(Real World) System (RWS): A collection of entities and processes that collaborate to accomplish a (real world) goal. An **entity** is any real or abstract thing about which system information is stored / manipulated. A **process** is a time-ordered sequence of events that describe the relationships between the system entities. An **event** is an entity activity that may change the state of the system. The system's **state** is that collection of information necessary to completely describe the system at any particular time.

Different ways in which a RWS might be studied:



Model: An abstraction of a RWS, used to focus attention on the system aspects important to the type of model being built (related to the reason for creating the model) and not to “reproduce” the system. A model includes enough information about the RWS entities, processes, events and states to emulate system “reality” and excludes information deemed to be irrelevant. Model process design requires inductive (specific => general; from experience & observation to general conclusion; the premises may predict a high probability of the conclusion, but do not ensure that the conclusion is true (see [Problem of Induction](#))) rather than deductive (general => specific; from laws, rules & widely accepted principles to specific solution; the conclusion is *necessitated* by, or reached from, previously known facts) reasoning. A model may be physical (e.g. a wind tunnel model) or conceptual (i.e. of the mind). Conceptual

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models might be explicit (expressible by a closed-form equation, when it exists, or by a numerical approximation – e.g. a computer simulation) or might be implicit (e.g. expressible by a diagram or text). Certain analytic models may incorporate both implicit and explicit techniques (e.g. computer-based multi-agent systems where agent actions depend on some form of (rule-based) reasoning).

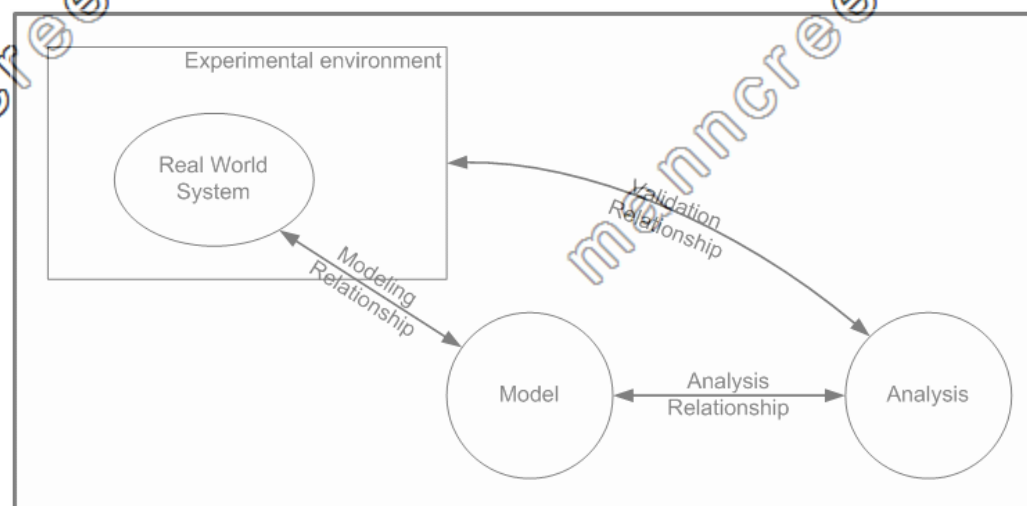
Simulation model: Any computational system capable of executing a model to generate its behavior. Analysts draw conclusions about a model by observing simulation results (accumulated model entity, process, event and state information), making it essential that the model be an accurate, in some sense, representation of the RWS (see “validation” and “modeling relationship” below). Similarly, the simulation must accurately carry out the intent of the model (see “verification” and “simulation relationship” below). Rigorous model verification and analysis validation leads to believable process understandings. Ultimately, simulations provide only estimates of RWS performance.

Model Verification: Ensuring that the problem is being solved correctly.

Analysis Validation: Ensuring that the correct problem is being solved. (In the *epistemological relativistic* sense, simulation model validation is possible only to the extent that domain, model and analysis experts can anticipate all the phenomena and interactions that significantly affect the system.)

Verification and Validation (V&V) taken together: The objective is to establish collaboration boundaries of trust between individuals making V&V model/prediction decisions (**decision makers** (responsible for assessing the compatibility and adequacy of models and characterizing the models and predictions used), **analyst** (responsible for assessing the compatibility and adequacy of models used and characterizing the models and predictions they create), **users** (trust decision makers and analysts)). V&V collaborations: (1) Behavioral Information Exchange: between decision makers and analyst that results in the communication of behavioral predictions from analyst to decision makers. (2) Behavioral Model Reuse: among analyst or scientists that results in the reuse of behavioral models or components of behavioral models. E.g. reference “[On Characterizing and Assessing the Validity of Behavioral Models and their Predictions](#)”, Richard J. Malak Jr and Christian J. J. Paredis, DETC2004-S7452.

Real World, Model and Simulation relationships:



Ref. (1)

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Notes on (Business) Systems Modeling and Simulation¹

Simulation / Model Classifications:

Continuous (system state changes continuously with respect to time) or **Discrete** (system state changes instantaneously at discrete times)

Static (no time dependence in model) or **Dynamic** (model is time dependent)

Deterministic (no modeled random components) or **Stochastic** (model has random components)

The business system simulation model types outlined below are in the **discrete, dynamic and stochastic** classification (*discrete-event simulation models*).

Some Types of Business System Models and Simulations (ref. examples on pages that follow):

Functional Process Models: processes directly related to the functional requirements of the system.

Value-centric: focuses on high level process values delivered to customers (e.g. a corporate-level vision).

Activity-centric: focuses on interaction of functional process activities and tasks (e.g. a process methodology).

Resource-centric: focuses on detailed functional process resource usage (e.g. a business process redesign).

Operational Process Models: processes directly related to the operational support of the system.

Infrastructure: focuses on process operational and surrounding framework support (e.g. modeling corporate-level operational process initiatives).

Run-time: focuses on implemented processes and their operational effectiveness (e.g. modeling Service Level Agreement responsibilities).

Some Reasons to Model / Simulate Business Systems:

Arrive at a better process understanding for complex systems; visualize system performance.

Help identify / classify system uncertainties as aleatory or epistemic.

Provide a focal point for stakeholder / supplier communication.

Identify hidden, emergent system behaviors.

Verify that stakeholder requirements are satisfied.

Test the impact of alternate system designs.

Some Common Mistakes in Modeling / Simulation:

Inappropriate level of details (to much, to little).

Unverified models (bugs, model errors).

Invalidated models (incorrect assumptions, model errors).

Improperly handled initial conditions (transient effects).

Short simulations (variance reduction).

Poor random number generation (use accepted and well known generator).

Improper seed selection (maintain stream independence).

Underestimate time and effort to complete (rely on system, model and analysis experience).

Lack of achievable goal(s) (specific, measurable, achievable, repeatable and thorough goals).

Incomplete mix of essential skills (leadership, system understanding, modeling expertise, programming ability).

Lack of client participation (iterate and increment).

Unexplained/unanswered results (verify and validate).

Not distinguishing epistemic (Bayesian solution techniques, subjective) uncertainty (deviates from reality because of a lack of knowledge about reality) from aleatory (Frequentists solution techniques, objective) uncertainty (deviation from reality because

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of natural stochastic behavior), and attempting to model epistemic with (e.g.) probability distributions functions when not warranted (isolate epistemic, gather more information (measure) and try to represent with distributions, determine sensitivity of model with respect to epistemic uncertainties).

Important Simulation Concepts:

Uniformly distributed and independent random number generation; different random number seeds (\Rightarrow independent variate generation).
Poisson arrival rates and, initially, exponential service time distributions (\Rightarrow IID).
Infinite queue sizes (\Rightarrow independent output data).
Transient effects suppression (\Rightarrow steady state output data).
Sufficient model replications of sufficient size (\Rightarrow variance reduction).
Independent and identically distributed simulation results (facilitates model comparisons).
Output data confidence intervals (facilitates model comparisons).

Typical Simulation Output Data Measures and Analysis Techniques:

Entity utilizations.
Item congestion, wait times, queue sizes and throughput rates.
Design change sensitivity.
Model operation optimization.

Typical RWS / Model / Simulation project checklist:

Project launch / risk phase

Specify overall vision within which this project fits.
Assemble project goal(s) from client requirements.
Select success evaluation metrics.
Select simulation detail level to match goal(s).
Determine system/model domain (extent) and boundary conditions.
Select proper leadership, modeling and system personnel to match goal(s) / detail level.
Select simulation tool(s) to match personnel, detail and project goal(s); verify quality.
Assign roles and responsibilities to personnel.
Estimate project time / cost to match tool(s), personnel, detail and goal(s).

Component design, build and test phase

Select appropriate model time frame.
Select appropriate process objects (items) to be tracked through the model.
Select appropriate item attributes to match model detail / goal(s).
Select appropriate model events and distributions to match model detail / goal(s).
Validate events / distributions with RWS.
Link model events to approximate RWS.
Model external actor events with appropriate distributions, interaction frequency; validate.
Ensure that input random numbers are independent and identically distributed (IID).
Regularly review the model / requirements / goal(s) with the client.
Document model rationale.

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Implementation, interpretation and maintenance phase

- Reaffirm transient removal time.
- Test simulation length.
- Analyze and interpret results; compare to RWS.
- Run sensitivity analyses as appropriate.
- Run optimization analyses as appropriate.
- Explain (verify/validate) any illogical results.
- Present results to client / stakeholders; re-evaluate / alter design decisions as appropriate.

Prototype vs. Pilot Model/ Simulation

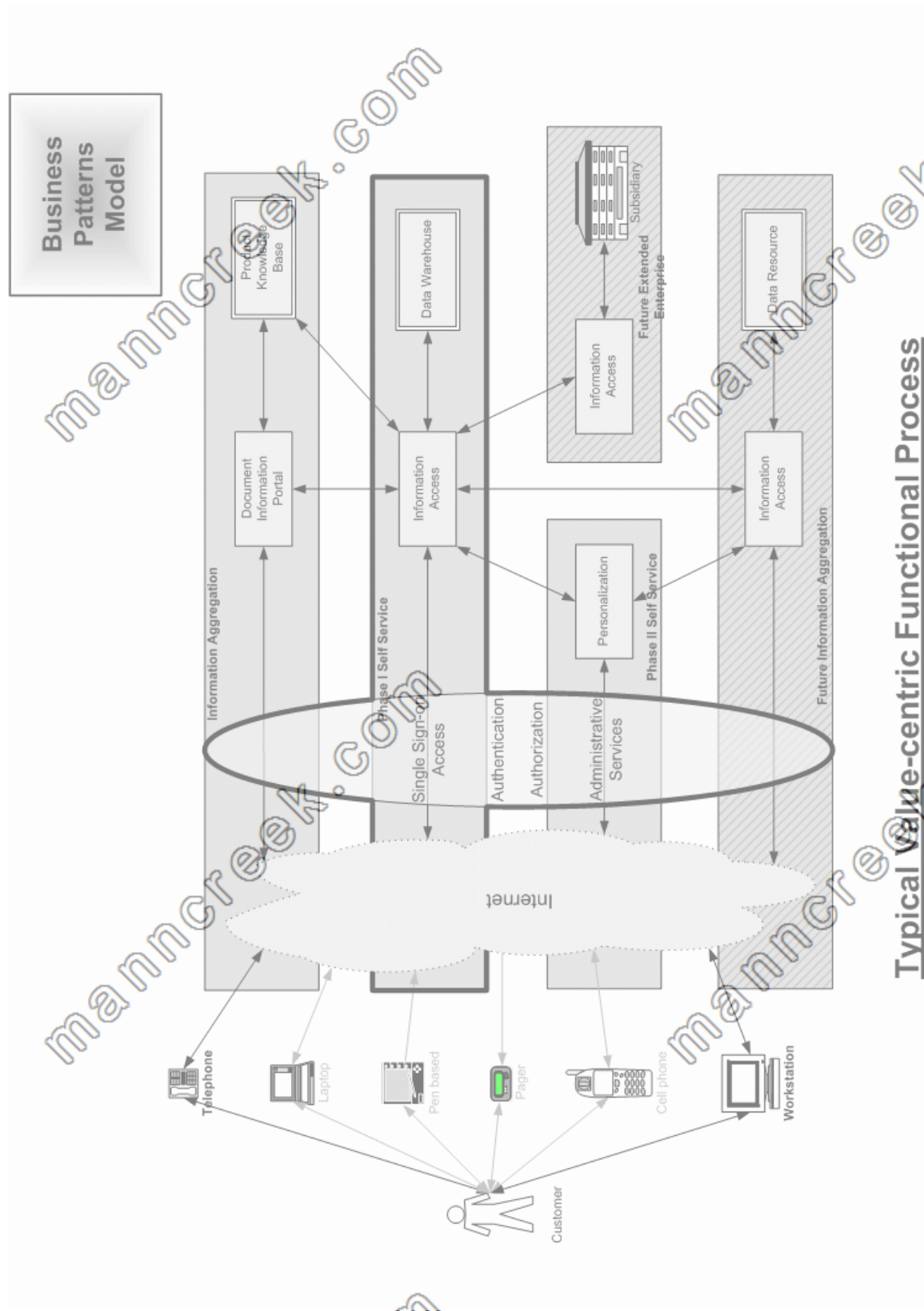
Methods of studying and confirming system requirements / design at an early stage of development.

Types of prototyping:

- 1) Mock-up (high level, superficial, e.g. to demonstrate workflow)
- 2) Functional (focuses on specific partial functionality – may be throw-away or skeletal).
- 3) Throw-away (quick-and-dirty to resolve risk, requirements, design, implementation).
- 4) Skeletal (to become the basis for / implemented in the production environment – a.k.a. Pilot).

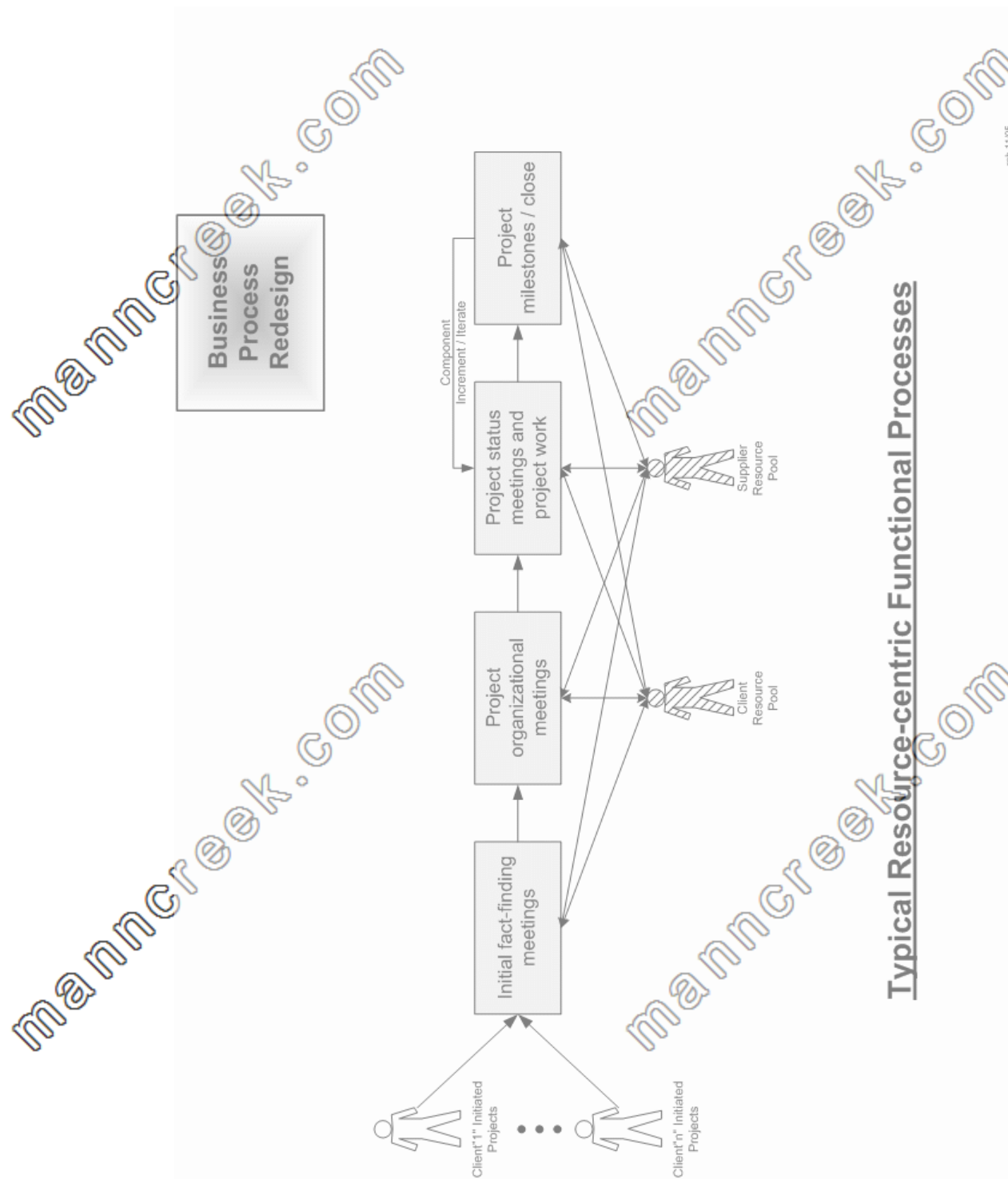
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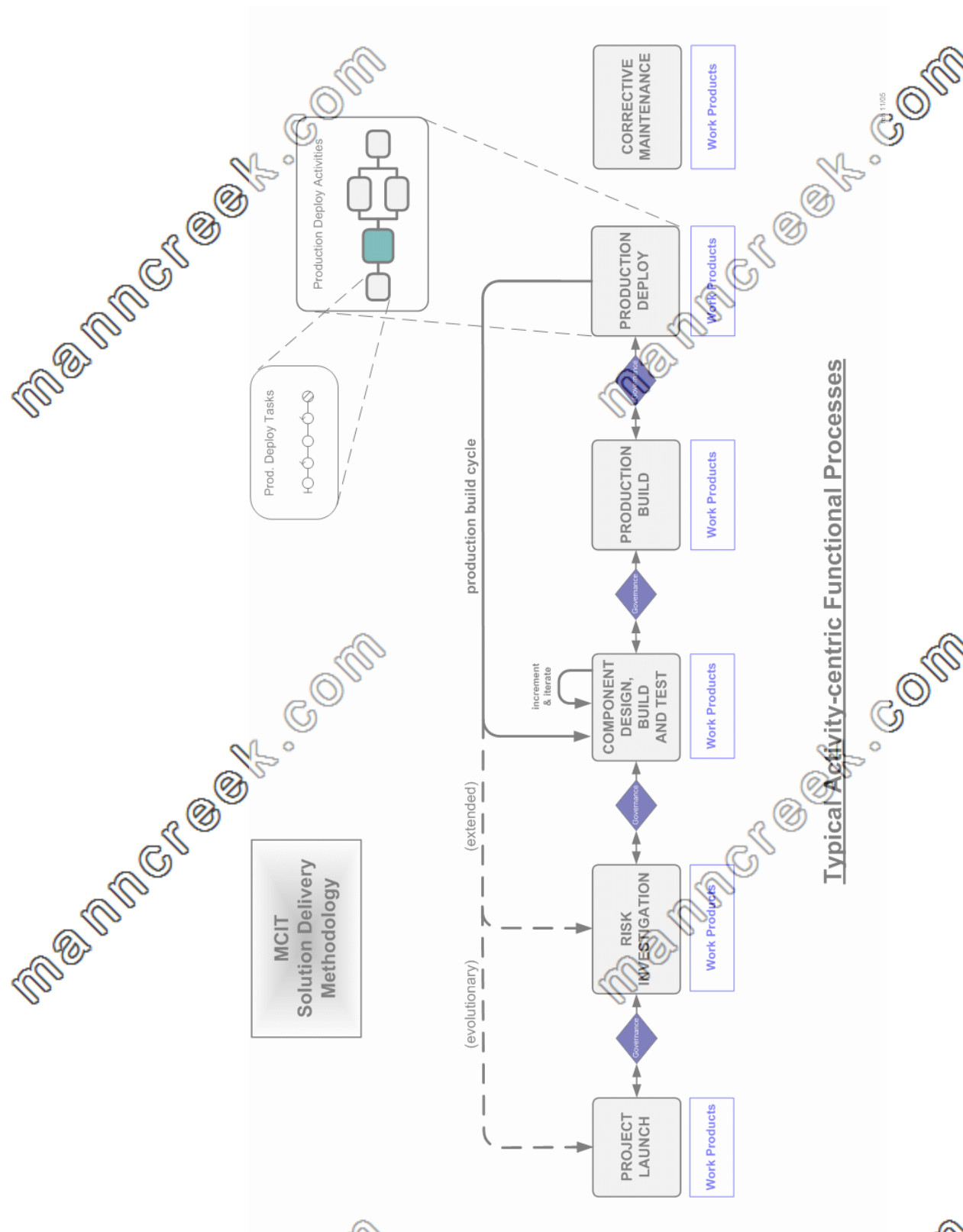
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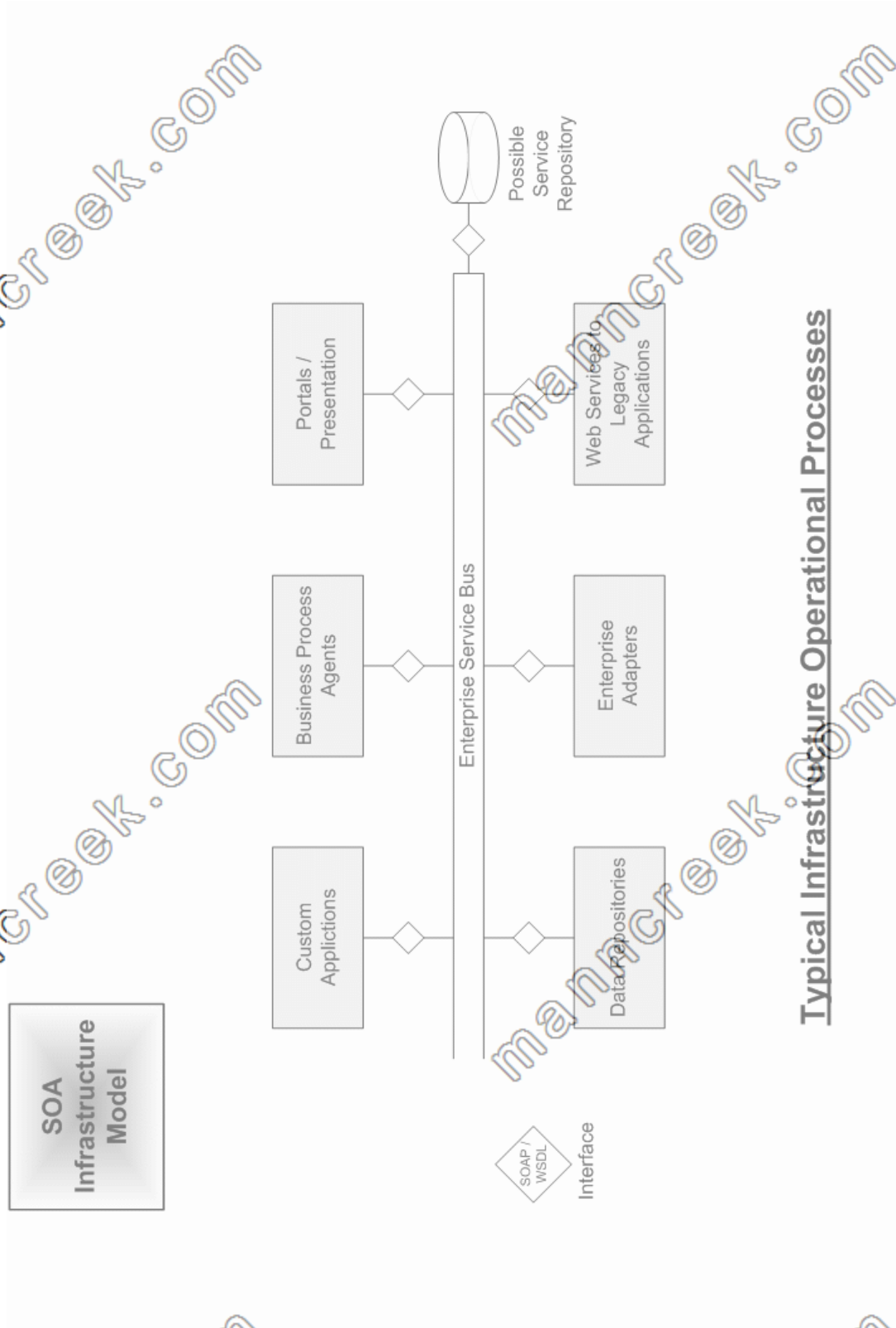
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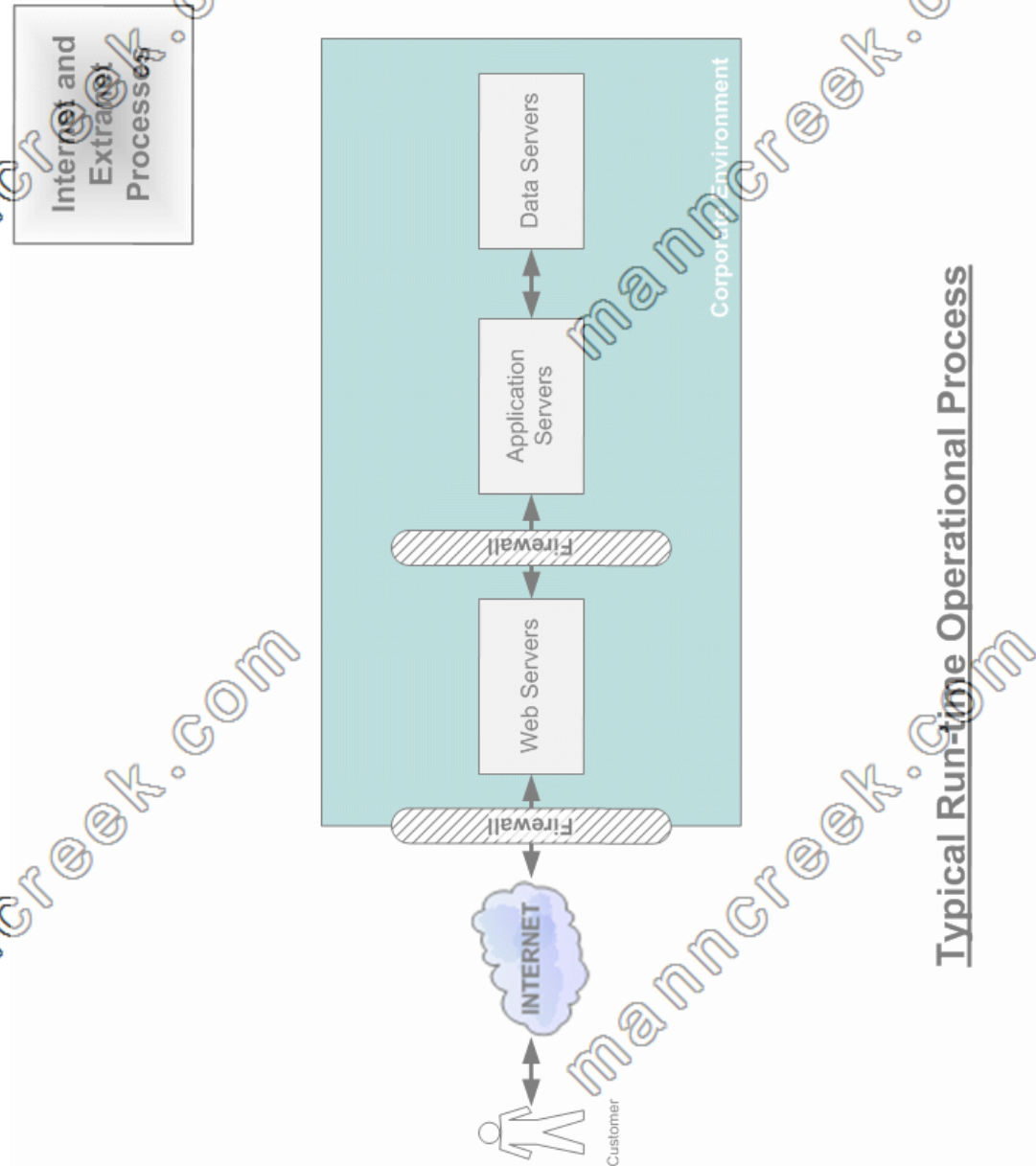
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