System Dynamics

2020.08

임정주 대표 (The TEAM)

1 Disruption Analysis

1) 분석방법

Based	Studies	Method
Productivity-based Methods	Project-specific studies	Measured mile analysis
		Earned value analysis
		Programme analysis
		Work or trade sampling
		System dynamics modelling
	Project-comparison studies	
	Industry studies	
Cost-based Methods	Estimated v incurred labour	
	Estimated v used cost	

- **논문*을 참고하면, 가장 많이 사용하는 방법은 Modified global method이며, 다음 방법은 Global method, Industry study의 순서임.**

- **성공경험과 관련된 응답은 Measured Mile이 랭크가 가장 높았으며, 다음은 Modified Global Method, Industry Studies의 순서임.** (2008년도 자료로 현재 Trend와는 약간 상이하나 System Dynamics는 그 사용빈도나 활용도가 증가하고 있음.)

* An investigation into the use of construction delay and disruption analysis methodologies, Nuhu Braimah, 2008

Methodology	Contractors		Consultants		Overall	
	Usage index	Rank	Usage index	Rank	Usage index	Rank
Modified Global Method	62.3	2	56.8	1	58.8	1
Global Method	65.3	1	54.5	2	50.9	2
Industry Studies and Guidelines	46.7	3	52.3	3	49.5	3
Measured Mile Technique	45.5	4	48.0	4	46.8	4
Earned Value Management	36.4	5	39.0	5	37.7	5
Time and Motion Studies	32.6	6	35.5	6	34.0	6
Systems Dynamics	23.9	7	28.4	7	26.1	7

Methodology	Contractors		Consultants		Overall	
	Success index	Rank	Success index	Rank	Success index	Rank
Measured Mile Technique	51.9	2	56.0	1	54.8	1
Modified Global Method	54.6	1	42.0	5	48.0	2
Industry Studies and Guidelines	46.5	3	49.2	3	47.8	3
Earned Value Management	39.2	5	51.7	2	45.7	4
Global Method	41.0	4	37.7	7	40.0	5
Systems Dynamics	27.0	7	46.0	4	36.6	6
Time and Motion Studies	33.7	6	39.0	6	36.4	7

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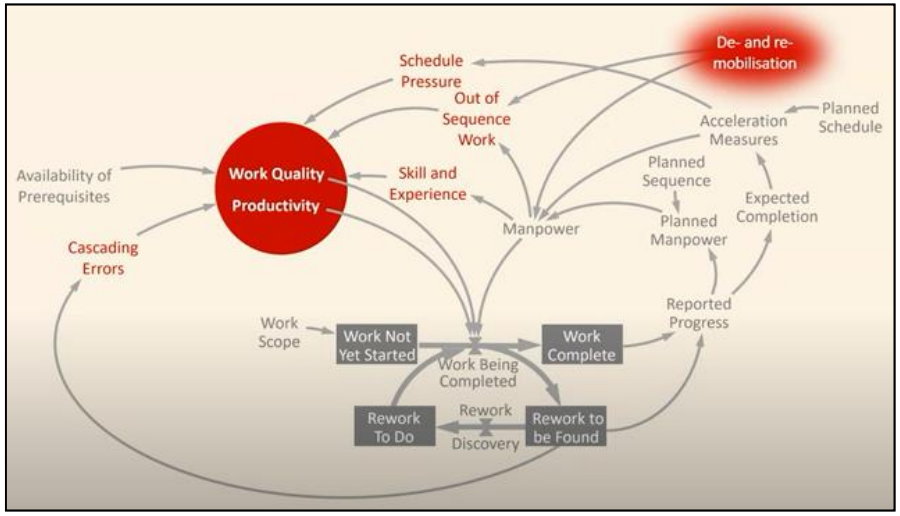
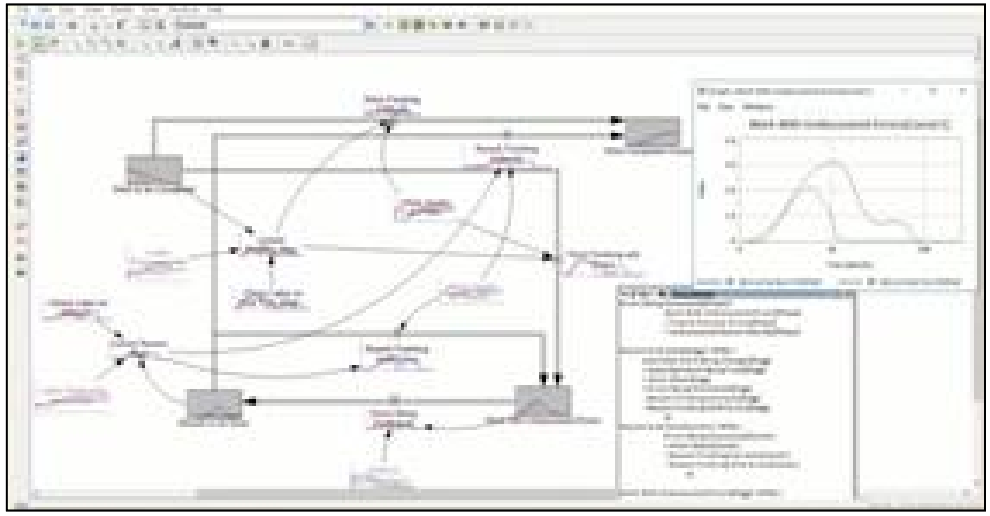
1) 개요

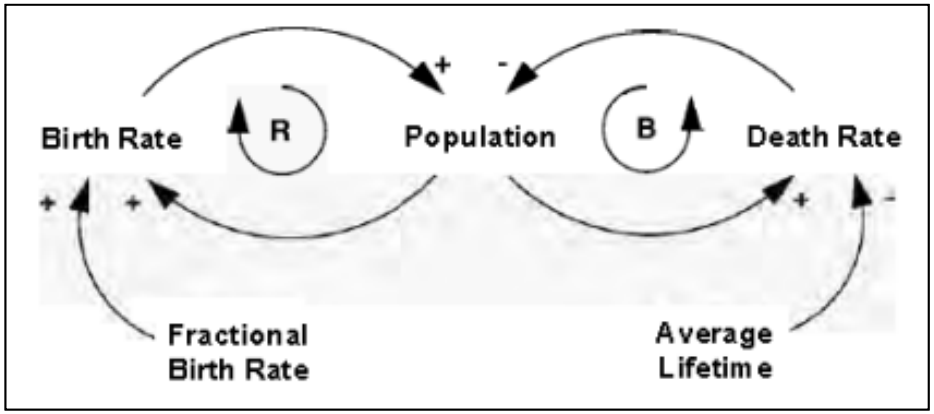
- System Dynamics(시스템 역학)은 컴퓨터 시뮬레이션 방법이며 1960년대 MIT에 의하여 개발 되었음.
- 시스템 내의 Feedback process에 초점을 두고 각 구성요소들 사이의 순환적 인과관계와 피드백을 강조함.
- 산업공학에 많이 사용되지만 기계, 건축, 도시공학 등 다양한 분야에 적용이 가능하며 최근 Disruption Claim에 있어서 많이 사용되고 있음.
- 2009년 ECRI(Engineering Construction Risk Institute)은 SD에 기반한 Tool을 Industry Best Practice로 인정했음.
- 2017년에 SCL(Society of Construction Law)도 Disruption을 분석하는 방법으로 인정했음.





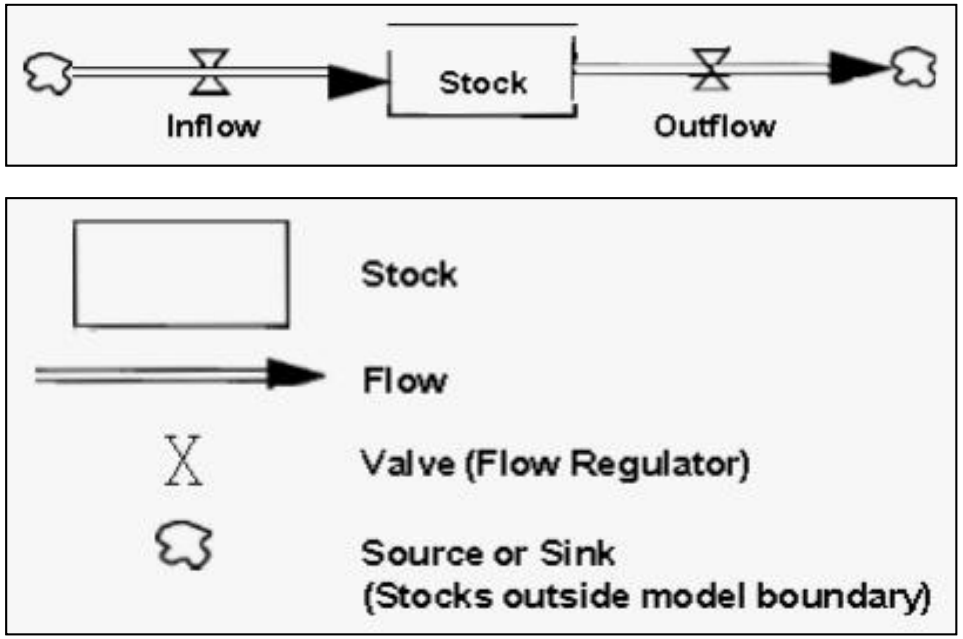
2) 주요개념

- **Casual Loop Diagram**



둘 간의 관계를 나타내는 Diagram 이며, 동일한 방향은 Positive 관계이고 반대 방향은 Negative 관계임

- **Stock and Flow Diagram**



초기 설정값과 Flow 비율에 따라 결과값이 정리되는 Diagram임

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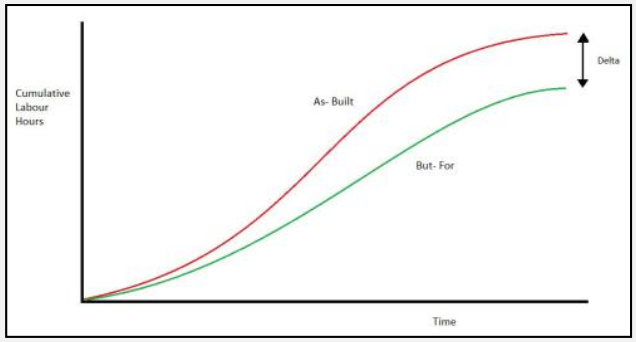
3) Proven by Computer? System Dynamics and Disruption Claims (Ralph Goodchild, SCL, 2018.09)

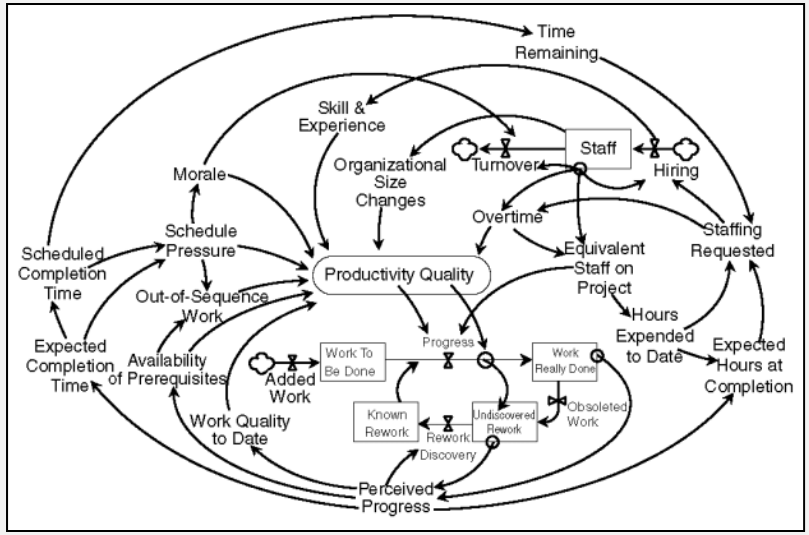
- SD는 프로젝트의 기록에 기반한 'But for' Simulation에 해당한다.



- SD는 2가지 점에 문제가 있는데, 하나는 프로젝트의 기록에 근거한 Parameter 값이 잘못 설정될 수 있다는 점이며 또한 Stocks and Flows에 결점이 있을 수 있다는 것이다.
- 영국법원에서는 비용이 합리적으로 설명된다면 Disruption Claim을 결정하는데 있어서 SD Model이 충분히 유용하다고 판단하고 있음.
- 아래 Case*에서 TCC (Technology and Construction Court)는 Disruption Claim을 다른 방법으로 분석할 수 없을 때 SD Model에 대해서 사용될 수 밖에 없는 불가피성을 이해하였음. (즉 개별적인 분석이 어려울 때 누적적인 Impact를 분석하는 것이 더 설득력이 있는 상황)

*Amey LG Ltd v Cumbria County Council [2016] EWHC 2856 (TCC)

- ICC Arbitration에서 SD Model은 적합한 방법으로 인정되었음.
- SD Model은 Re-work cycle에 기반하는데, Schedule은 어느 정도의 Re-work은 이미 고려하여 반영된다.



- SD Model은 개별적인 이벤트의 Simulation을 포함하여 여러 Simulation이 같이 제시되는 편이 바람직하다.
- SD Model은 아직까지는 법원에서 자주 적용되는 편은 아니지만, 중재에서 증거자료로 많이 활용되고 있다.

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4) Program

Package name	Website	Licensing	Last update	More info
Analytica	https://analytica.com/	Proprietary, commercial, free limited version	2018	Supports system dynamics, Monte Carlo simulation for uncertainty, array abstraction for handling multidimensional data, linear and non-linear optimization. Uses influence diagrams to define, navigate, and document models.
AnyLogic	https://www.anylogic.com/	Proprietary, commercial, free Personal Learning Edition (PLE) for education, formal or not	2020	Supports system dynamics, agent based and discrete event modeling, allows making hybrid models.
GoldSim	https://www.goldsim.com/	Proprietary, commercial	2019	Differs from traditional system dynamics approaches in that 1) it puts much greater emphasis on probabilistic simulation techniques to support representation of uncertain and/or stochastic systems; and 2) it provides a wide variety of specialized model objects in order to make models less abstract and help represent processes and events that cannot easily be represented using a traditional system dynamics approach.
Insight Maker	https://insightmaker.com/	Free, Insight Maker Public License (GPL adjusted)	2017	Insight Maker supports System Dynamics modeling: a powerful method for exploring systems on an aggregate level. It is 100% browser based with an open support group using Google mail list.
ISSE Player (Stella)	https://www.iseesystems.com/	Proprietary, commercial	2018	System dynamics and discrete event modeling with some agent-based capabilities. Drag and drop user interface builder allows simulations to be published online. Includes multilevel hierarchical models, reusable modules, multidimensional arrays, optimization, and Monte Carlo analysis.
LOOPY	https://ncase.me/loopy/	Free, CC Zero license	2019	A tool for thinking in systems. Users draw circles and lines to build an interactive simulation of a complex system.
Powersim Studio	https://www.powersim.com/	Proprietary, commercial, free limited version	2018	Supports system dynamics; building graphical diagrams using stocks and flow, including delays and feedback for non-linear models. Supports units, multi-dimensions running scenario simulations and Monte Carlo simulations.
Simantics System Dynamics	http://sysdyn.simantics.org/	Free, Eclipse Public License (EPL)	2018	Free and open source system dynamics modelling software with stock and flow modelling, hierarchical models and array variables.
Vensim	http://vensim.com/	Proprietary, commercial, free Personal Learning Edition (PLE) for education and personal use	2020	Continuous simulation with stocks and flows, some discrete delay and discrete event functionality. Flexible array syntax with mapping among dimensions

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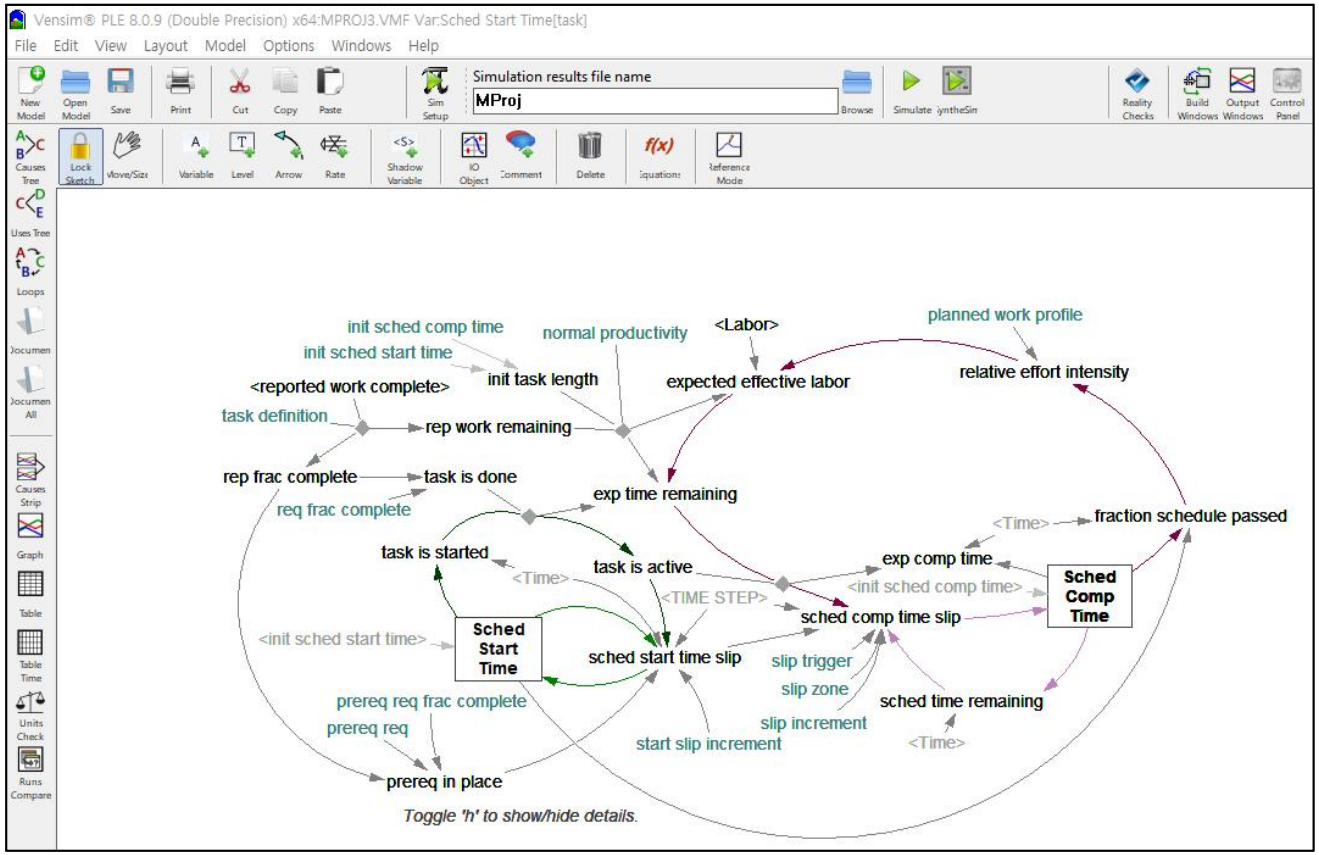
5) 검토 순서

1. Become acquainted with the problem
2. Dynamic problem definition
3. Draw the causal loop diagram
4. Construct the stock-and-flow diagram
5. Estimate the parameters
6. Run the model to get the reference mode
7. Model validity and sensitivity analysis
8. Testing the impact of policies



- Vensim program : http://vensim.com/download/

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6) 최근 적용 사례

'Tuxedo Park': 100% disruption recovery!

- Tuxedo Park was a design-bid-build development in the MENA region, budgeted at about $1bn, that:
  - Overran its budget by $500 million
  - Finished 2.5 years late
- The Contractor "knew" that the Employer had substantially impacted the project, but conventional analysis and the existing data trail did not (appear to) support this view.
- Yet, a forensic analysis using Dynamic Disruption Analysis proved that 60% of the overrun had been caused by the Employer.
- In **international arbitration**, the tribunal decided that the evidence produced by the analysis was credible and defensible, and awarded the Contractor **full recovery of the Employer-risk disruption**, as determined in the System Dynamics model (i.e., the entire 60% of the overrun.)

'Petrochem Refinery': a quick settlement!

- The 'Petrochem Refinery' was a design-bid-build subcontract within a major oil & gas infrastructure project in the MENA region, budgeted at about $300mn.
- It suffered significant overruns, and the Subcontractor argued that these had been caused by the main Contractor.
- When an initial round of negotiations failed to settle the issue of disruption costs, the Subcontractor decided to engage CDS and use System Dynamics to produce a more defensible claim.
- The main Contractor opposed the new claim, and especially the Subcontractor's use of SD.
- However, our client shared with the main Contractor information about the assessment: the steps followed, the data used, the questions asked… … and **within a month of starting the assessment**, both parties **settled** their differences. "

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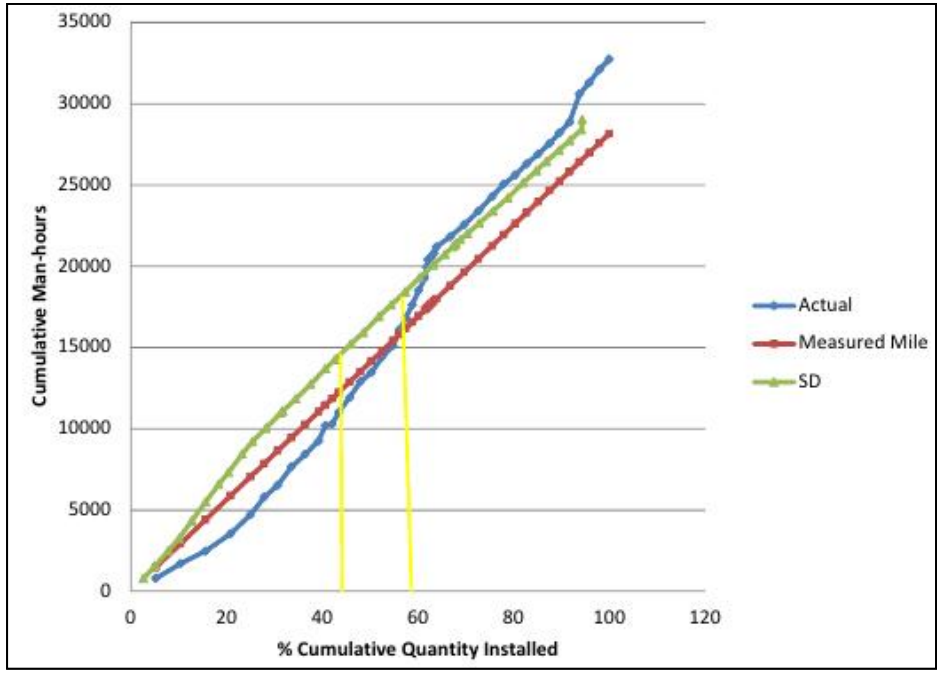
7) Example 1*



week	Work hours	Quantity installed	Should have - Measured Mile	Inefficient Work (Measured Mile)	Work hours-SD
13	745	1170.33	395.69	349.31	111
14	902	1885.92	637.63	264.37	745
15	970	1885.92	637.63	332.37	902
16	550	1885.92	637.63	-87.63	970
17	958	1885.92	637.63	320.37	550
18	704	1885.92	637.63	66.37	958
19	987	1110.80	375.56	611.44	704
20	710	1110.80	375.56	334.44	987
Total	6526		4334.96	2191.04	5927

- **실제 투입된 Manhour는 6,526시간이며, Measured Mile로 확인된 Manhour는 4,334시간이었음. 따라서 시공자는 이 차이인 2,191시간을 클레임으로 청구하게 됨.**
- **그러나 SD Model로 계산된 적정한 Manhour는 5,927시간이며, 실제 투입된 6,526시간과의 차이인 599시간은 정당화되기는 어려움. 결국 2,191시간과 599시간의 차이인 1,592시간이 합리적인 수준으로 추정됨.**

* Dynamic Modeling Approach to quantify change orders impact on labor productivity, Zain Ghazi Al-kofahi, 2016

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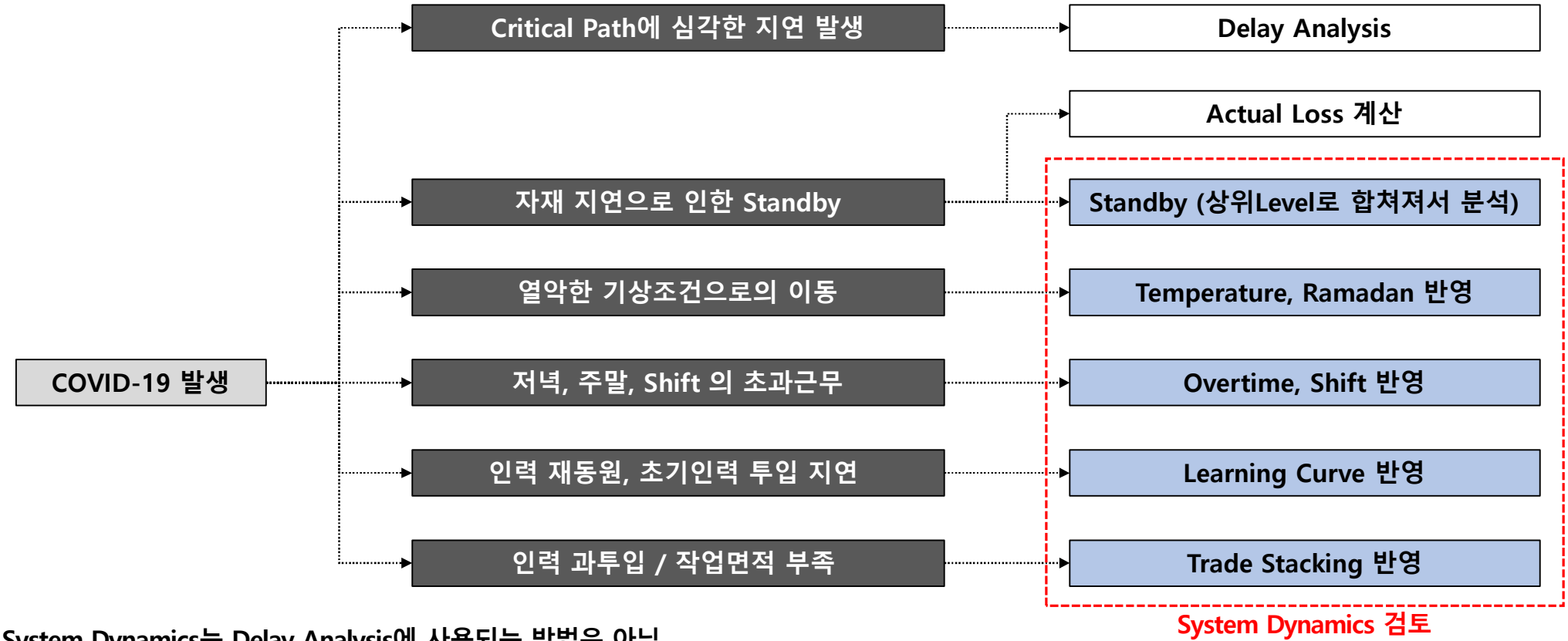
8) Example 2



- System Dynamics는 Delay Analysis에 사용되는 방법은 아님.
- Event 성으로 발생한 사건은 개별적인 Actual Loss를 계산하는 것이 더 합리적임

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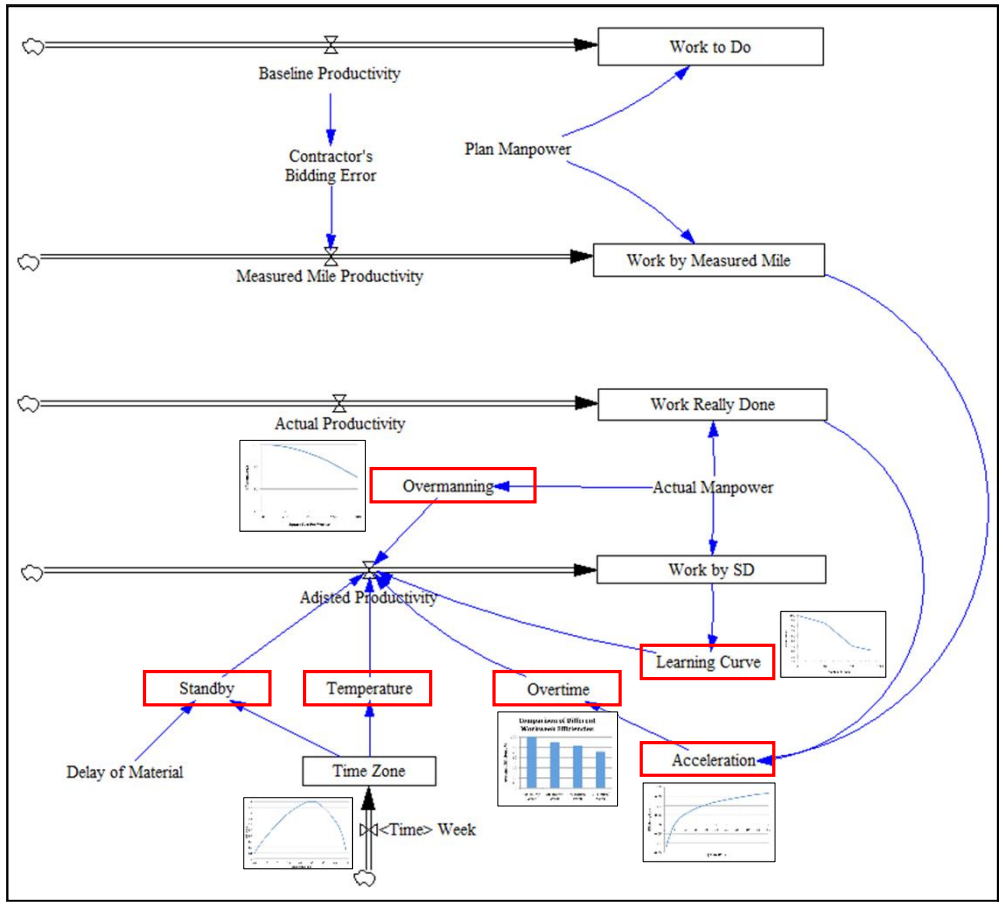
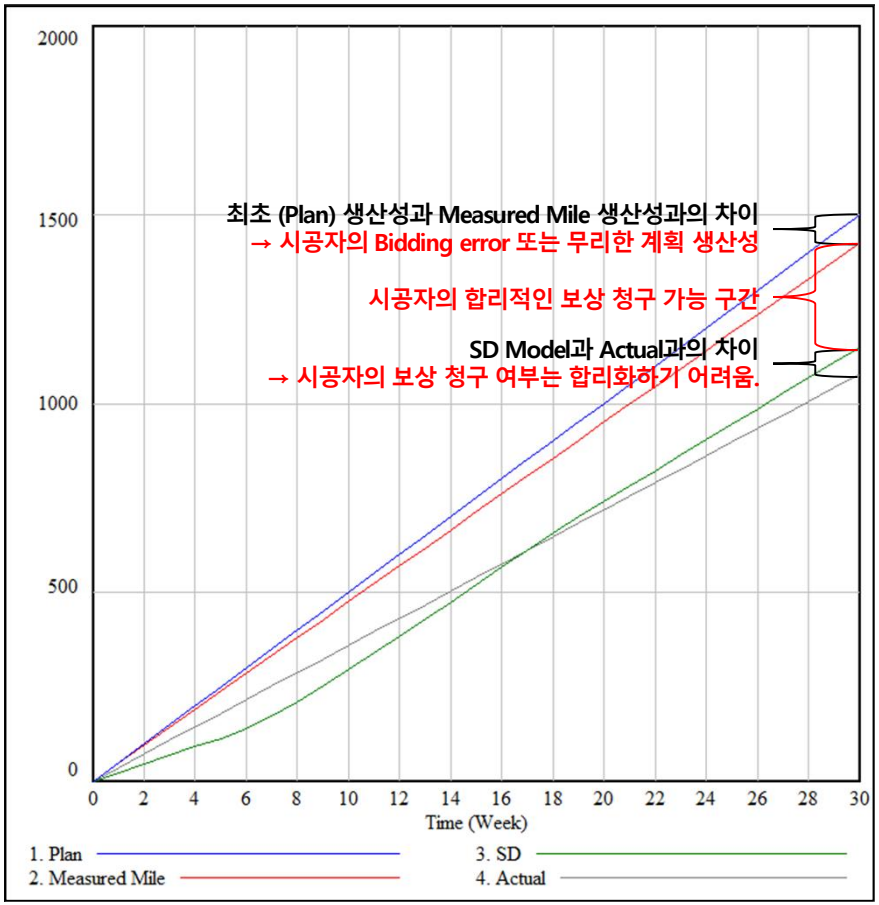
8) Example 2





8) Example 2

System Dynamics.mp4

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9) Summary

No.	구분	적용 방향	Remarks
1	**적절한 방법으로의 활용 가능성**	• 중재단계에서 활용이 증가하고 있으며, 향후 활용이 점차적으로 증가할 것으로 예상됨. • 건설산업의 특성상 (복잡성, 상호 관련성) SD의 개념은 논리적으로 상황을 잘 설명할 수 있기 때문에 잘 적용된다면 적절한 방법으로 사용 가능함.	효과적으로 잘 설명하느냐 여부가 중요함
2	**적용 순서**	• 1단계 : 개별적으로 분석이 가능한 상황은 먼저 개별적으로 분석 • 2단계 : 개별적인 분석이 어려운 상황에 대하여 종합적이고 누적적인 피해분석을 위하여 SD 적용 가능성 검토 • 3단계 : Measured Mile과 같은 다른 방법과 병행하여 SD modeling 검토 • 4단계 : 여러 분석결과를 비교하여 합리적인 Damage 산출	SD Modeling을 거치면 Amount는 적어지나 그만큼 합리적인 편임
3	**Data**	• SD는 2가지 Data의 Parameter와 Value를 결정해야 함. 1. Actual Data : 현장에서 실제 투입한 Manpower와 Quantity 2. 각 Cause에 대한 생산성 저하 값, 발생 조건, 결과 등 • 이러한 Data 값들이 인위적으로 결정되면 안 되며, 충분하고 합리적인 근거가 확보되어야 함.	
4	**COVID-19**	• Examaple-2에서 설명된 최소한의 도해는 최소한의 원인과 결과에 따라 연관관계를 가지고 있는 작업들로 이후 추가 원인, 추가 결과에 따라 확장되어 분석이 가능함. • SD는 Actual Data에서 검토가 시작되기 때문에 Actual Data 정리, 확보가 필요함. • SD만으로는 해결책이 될 수 없으며, 다른 Alternatives와 병행하여 분석이 필요함.	