

System Dynamics Modeling and Simulation for Reduction of Scrap and Rework in an Automotive Manufacturing Company

Shelly Mona

Department of Industrial Engineering
Tshwane University of Technology
Pretoria, South Africa
shellyt.mona@gmail.com

Abstract

Scrapping and rework are a manufacturing reality that influences the automotive manufacturing industry. This research utilizes System Dynamics modeling and simulation tools to study the causalities and feedback relationships for defects which contribute to the scrapping and rework of vehicles in an automotive manufacturing company based in South Africa. It also recommends remedies for scrap and rework reduction. The causes of defects were identified by consulting the company documents, and the cause and effects and improvement feedback relationship were explored using system dynamics (SD) models. The SD simulation models were created following the five steps of the system dynamics modelling process, namely problem articulation, formulation of a dynamic hypothesis; formulation of a simulation model; testing of the model; and policy design and evaluation. Based on identified root causes for defects and the simulation results, resources and techniques for process improvement were recommended. The paper demonstrates the usefulness of system dynamics modelling tools for solving problems in the automotive manufacturing sector. Building simulation models can reveal previously hidden relationships, provide systematic ways to analyse manufacturing defects, and allow the user to test effects of different alternative scenarios without having to make changes to the real system

Keywords

Modeling and Simulation, System dynamics, and Scrap and rework

1. Introduction

Scrapping and rework cost the automotive industry billions every year, while the price paid by companies for poor product quality is steep. Even though most businesses think they account for re-work and reject rates, the consequences are usually much more far-reaching. In fact, rework and scrapping issues influence the quality, delivery times, sales and crucially, brand image. As such, it is no surprise that every company's goal is to produce high-quality products at the lowest possible cost (Kcprofessional 2015). While many types of research performed up to the present have proved that scrapping and rework can be reduced through the implementation of quality control tools, a few types of research precisely investigate the factors that contribute to scrapping and rework using the system dynamics modeling and simulation tools in the automotive manufacturing industry. "SD is the study of the information feedback characteristics of industrial activity to illustrate how organisational structure, changes in policies, and time delays in decision and actions interact to affect the success of the organisation" (Khakifirooz et al. 2018). Building simulation models can reveal previously hidden relationships, provide systematic ways to analyse manufacturing defects, and allow the user to test effects of different alternative scenarios without having to make changes to the real system (Strandhagen et al. 2020).

The case company is one of the biggest automotive manufacturing companies in South Africa with ISO 9001 standards certification and traces its roots all the way back to 1911. Yet they face manufacturing defects, which results in part scrapping, part reworks, vehicle reworks, and vehicle scrapping. These costs the company lot of money based on the internal cost of non-conformance paid for reworks and scrapping of parts and cars in order to avoid external failure costs that will be transferred to customers, thus generating liabilities that affect warranty work.

1.1 Objectives

This research aims to identify causes of defects, develop a system dynamics model for studying the causalities and feedback relationships for defects, which contributes to scrapping and rework of vehicles, and recommend remedies for scrap and rework reduction in an automotive manufacturing company based in South Africa.

2. Literature Review

Manufacturing systems can be very complex and difficult to analyse. Thus, modelling and simulation are widely used for solving production system problems (Kampa et al. 2017). Simulations allow organisations to assess new policies and strategies in their systems before the change are applied in real life. System dynamics (SD) and discrete event simulation (DES) are two modelling approaches widely used for simulation of manufacturing systems (Antonelli et al. 2018). Nonetheless, the goals of SD and DES are different. When it comes to modelling and simulation of defect reduction, system dynamics provide effective tools to study cause and effect relationships (Thompson and Bank 2010). System Dynamics is a computer-aided approach to policy analysis and design used to analyse and solve complex problems with a focus on policy analysis and design through understanding the dynamic behaviour of systems (Dung Ho et al., 2018). In SD, several diagramming tools are used to capture the structure of systems, including causal loop diagrams and stock and flow maps. Casual Loop Diagrams (CLD) are used for representing the feedback structure of systems and the casual relationship among the system variables and stock and flow diagrams for obtaining variables in mathematical equations (Sterman 2000). "SD model development involves a number of iterative steps ranging from knowledge elicitation and qualitative modelling to simulation of alternative scenarios" (Derwisch and Lowe 2015). System dynamics models are created from five stages: problem articulation, formulation of a dynamic hypothesis, formulation of a simulation model, testing of the model, and policy design and evaluation (Sterman 2000).

3. Methods

The type of research undertaken in this paper constituted a quantitative study and a model building study. Quantitative data consists of analyses, graphs and tables that generate or use numerical data; it examines relationships between variables, which are measured numerically and analysed using a range of statistical and graphical techniques (Saunders et al 2016). The quantitative method incorporates controls to ensure the validity of data. Model building studies are aimed at developing new models and theories to explain phenomena.

The company, a large automotive firm, has already used several quality management tools such as check sheets, cause and effect diagrams, Pareto charts and flow charts. These tools are important for the day-to-day management of large automotive manufacturing plants, but they do not capture the dynamic complexity of the defect creation process. Internal company documents (quality audit reports, root cause analysis and countermeasure reports, and operation sheets) were studied and analysed to explore the manufacturing processes in order to identify and understand the root causes of defects that result in scrapping and rework in an automotive manufacturing company based in South Africa. Descriptive statistics was used to collect, summarise data and present the results in appropriate tables and charts. The system dynamics modeling, and simulation tools was used to learn how the aspects identified from the company documents affects scrap and rework and to develop recommendations for improvement.

The study involves an analysis of the complex dynamic behaviour of the system in terms of the related process parameters in order to provide recommendations for process improvements using SD models. The six defects that contribute the most to scrapping and rework in an automotive manufacturing company were utilised for the purpose of this study. As such, the domain of the study is a set of rejection data of the vehicles and the production process and their physically significant parameters. To perform the analysis, SD models were established in the Stella software version 9.1.4. Stella is a program designed by Isee systems dedicated to increasing an understanding of systems through modelling and simulation, which enables one to study the dynamic nature of a system. The software is focused on system dynamics, it offers numerous ways of modelling to capture the real situations using causal loop as well as stock and flow diagrams. The user interface is divided into four basic parts consisting of a map for the development of the model, modelling parts allowing input of functions, constants in model variables, an interface displaying the simulation results, and the equation editor showing all the equations used in the model. During the modelling process, the application alerts users of errors and mistakes that must be revised before running the simulation; otherwise, the simulation cannot run. Thus, fundamental modelling mistakes can be avoided (Bureš 2015).

The feedback provided by the models helped to understand the defects from a system perspective. The flow model (Figure 1) of the methodology followed the iterative steps as described by Sterman (2000) in his book entitled Business Dynamics.

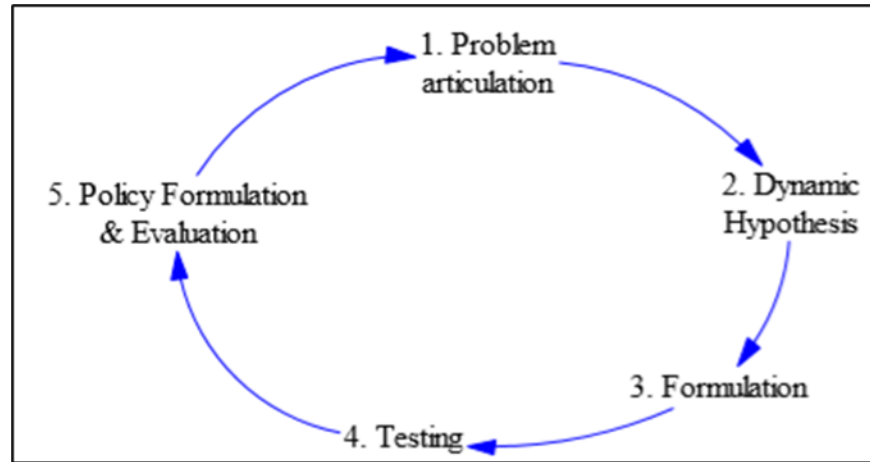


Figure 1. The five steps of system dynamics modelling (Sterman, 2000)

4. Data Collection

In the open market, the interior and exterior appearance of a vehicle is almost as imperative as its mechanical condition. The vehicle units are rejected against a defined checklist that forms the acceptance or rejection criteria. If the vehicles fail to meet any of the criteria of the set specifications on the checklist, it is rejected, and it will either be scrapped or reworked. For defect analysis, twelve months' rejection data have been collected. Table 1 and figure 2 shows the rejection data and defect data for twelve months respectively.

Table 1. Rejection data for twelve months

Month	Total Production	Total OK	Rejection	Dent	High Spot	Sealer Damage	Dirt	Poor Fit	Second Paint Damage	Other
Feb-18	1700	977	723	110	34	18	81	74	150	256
Mar-18	1700	1234	466	92	38	23	66	31	94	122
Apr-18	1700	1175	525	88	21	27	110	42	109	128
May-18	1700	1321	379	74	17	23	64	36	70	95
Jun-18	1700	1343	357	52	22	32	58	24	52	117
Jul-18	1700	1381	319	59	20	15	38	26	40	121
Aug-18	1700	1447	253	36	18	12	38	26	32	91
Sep-18	1700	1382	318	57	17	25	23	20	68	108
Oct-18	1700	1292	408	55	20	36	43	48	65	141
Jan-19	1250	884	366	47	24	23	29	43	102	98
Feb-19	1700	1410	290	44	17	21	44	16	48	100
Mar-19	1700	1403	297	16	21	28	55	9	35	133
Total	19950	15249	4701	730	269	283	649	395	865	1510

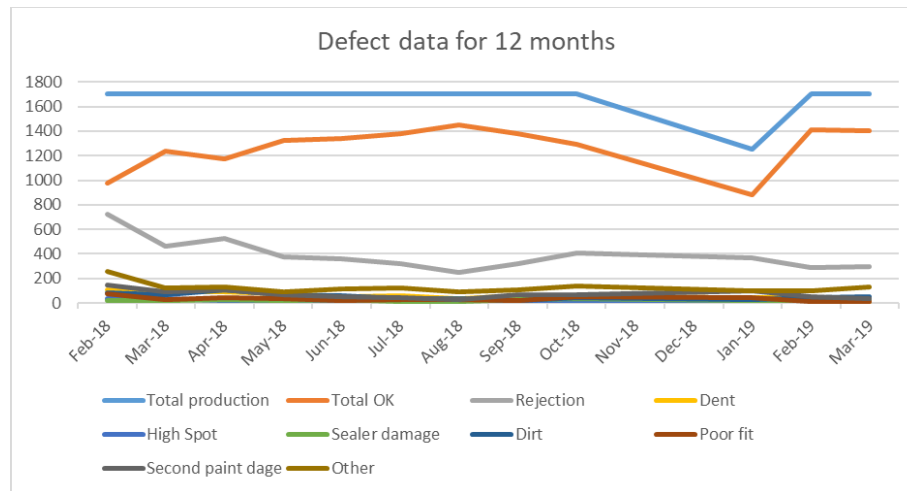


Figure 2. Defect data for twelve months

Based on Table 1, it is comprehended that most rejections arise due to dents, high spot, sealer damage, dirt, poor fitting of parts, and secondary paint damage. The average rejection rate for twelve months was calculated to be 23.5 %.

$$\text{Rejection rate} = (\text{Total rejection}) / (\text{Total production}) \times 100$$

$$= 4701 / 19950 \times 100 = 23.5\%$$

The company cause and effect diagrams were used to identify possible root causes for defects. Table 2 illustrates the summary of the root causes of the six defects that have been identified from the cause and effect diagrams

Table 2. Summary of root causes

		Cause			
		Man	Method	Machine	Environment
Effect	High spots	Dirty PPE	—	Dirty machines press and conveyors	Dusty environment
	Dents	Operator errors, poor rework skill, and poor packaging	—	Press machines, and jigs worn out	—
	Second paint damage	Incorrect loading and off-loading of vehicles, poor repairs, improper material handling	—	—	—
	Sealer damage	Operators not following correct processes	—	Spatula worn out	—
	Dirt	Dirty PPE	—	Dirty machines and jigs	Dusty environment
	Poor fit	Operator errors, and operators not following SOS	No proper WI in place	—	—
	Other defects	Operator errors, and operators not following correct processes	—	Press machines, tools and jigs worn out	Dusty environment

5. System Dynamics Modeling

The formulation of a dynamic hypothesis involves the generation of an initial hypothesis and mapping based on known theories of the problematic behaviour (Sterman 2000). A literature study was conducted to gain further knowledge of the subject matter and to identify the vital elements for inclusion in the model. The model was developed based on the primary variables that are believed to have a direct interrelationship with defect creation in the case company. This section describes and discusses the system dynamics tools employed in the study. The two subsections explain the concepts of stock and flow diagrams along with the formulation of the stock and flow diagrams.

5.1 Stock and flow diagram

To find an appropriate solution to tackle the problem of defects, two SD models for defect creation and defect reduction were built and analysed. In order to build these models, an extensive interaction with the production and quality team was necessary, which helped to visualise the model. The structure of the models was derived from the primary data collected, that is, the company defect data and the cause-and-effect diagrams. While developing the stock and flow diagrams, initially, the variables and their influences observed in the company documents were identified. The key elements of the system dynamics model concerning the investigated problem are depicted in Figure 3.

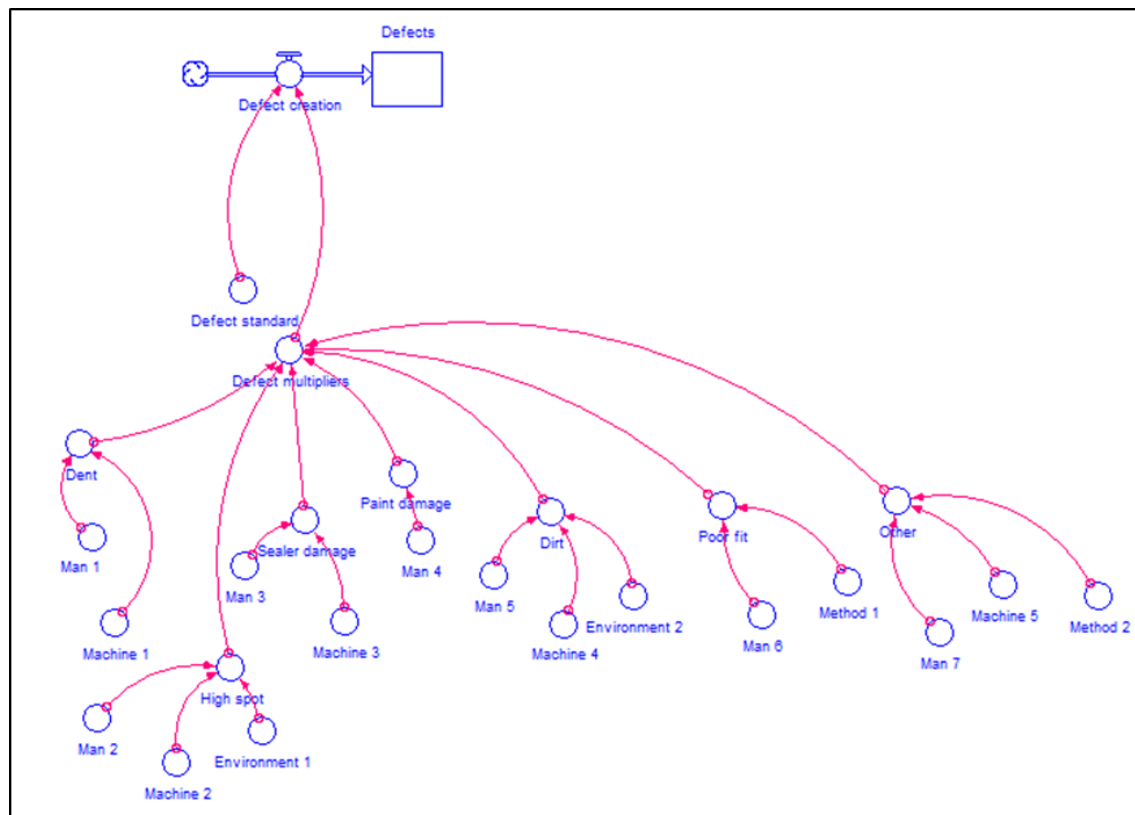


Figure 3. The key elements of the system dynamics model concerning the investigated problem

The main stock is Defect that is influenced by defect creation and defect standard. Defects are classified into 3 categories: Important A, Important B and minor defects. The nature and severity of a defect determines the defect standard or tolerance. Minor defects are usually small, insignificant issues that do not affect the function or form of the product. In most cases, the customer would not even notice a minor defect in a product. The tolerance for these defects is 1% of Total production. Important A and B factors are more serious than minor defects as they significantly depart from the product specifications expected by the buyer and may put customer safety at risk. There is zero tolerance for such defects. For the purpose of this study, the standard for minor defects (1% of total production) was used as the defects being studied do not affect both the functionality and safety of the product.

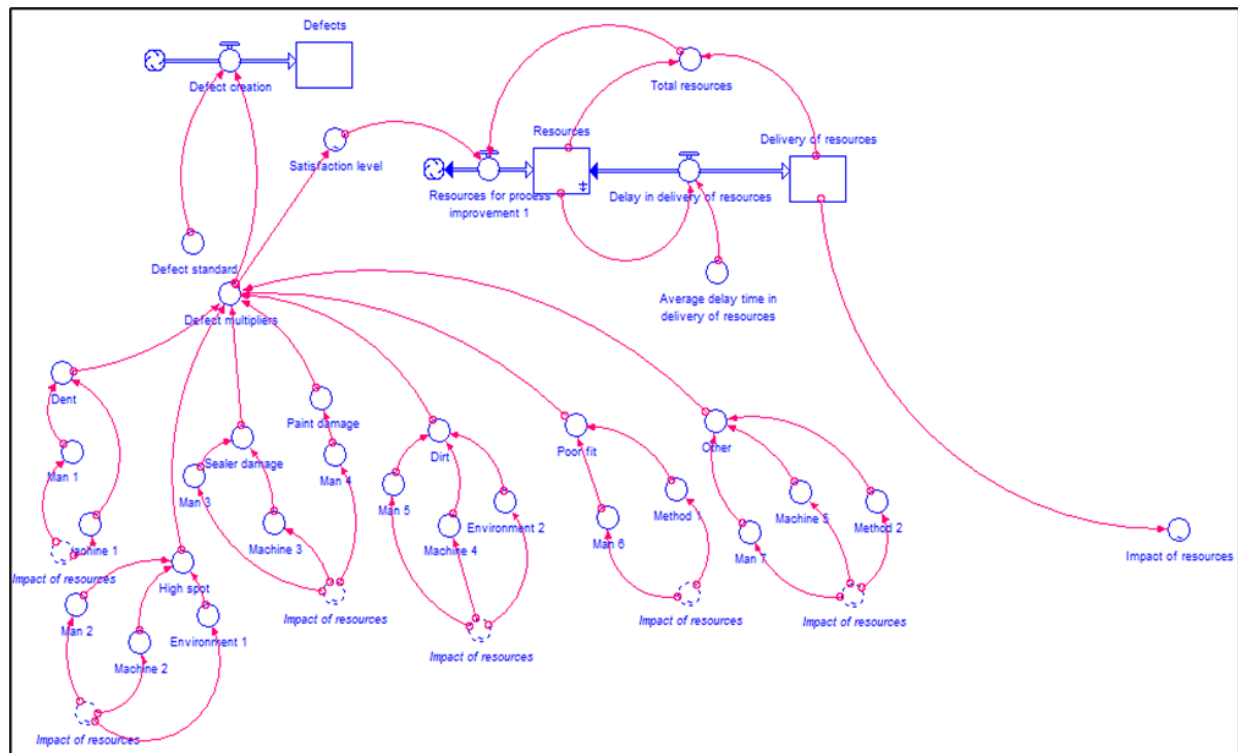


Figure 4. Stock and flowing diagram for defect reduction

The figure 4 includes subsystems dealing with higher-order material delays of the delivery of resources, as the delivery of resources is expensive while it takes time to plan and process the budgets. A person or organisation can define resources as a stock or supply of money, materials, staff, and other assets that can be drawn on in order to function effectively (Resource 2020). A delay is a process whose output lags its input in some manner. In higher order material delay, mixing and slight differences in the individual processing times occur, causing some variance in the supply of deliveries. It consists of several stages of processing in which items flow sequentially from one stage to the next (Sterman 2000).

For the purpose of this study, the term ‘resources’ refers to the financing of the implementation of planned and preventative maintenance, employee training and development, employee incentives, and motivation, depending on the nature of the root cause. The delay subsystem consists of two stages of processing, that is, stock dealing with the processing of resources as well as the delivery of resources. Resources flow from stock dealing with the processing of resources to stock dealing with the delivery of resources. The input to the second stage is the output of the first stage.

The average delay in the delivery of resources is proportional to the stock of resources in transit:

$$\text{Delay in delivery of resources} = \frac{\text{Resources}}{\text{Average delay time in delivery of resources}}$$

The total stock of resources in transit is the sum of the stock of the resources in each in transit at each stage:

$$\text{Total Resources} = \sum_{i=1}^n \text{Resources in transit}$$

Resources for process improvement depend on the satisfaction level. The lower the satisfaction level, the more resources needed for process improvement.

The impact of resources on defects is dependent on the delivery of resources. The more resources that are delivered, the higher their impact on defects. At a certain level of satisfaction, the resources for process improvement are

reduced. This means that management can deal with more defects, thus reducing the resources for process improvement and those resources are used elsewhere. Thus, fewer resources will increase the number of defects.

5.2 Formulation

The information was obtained from the data collected during the problem articulation stage. In some cases where data are not available, estimations were made based on knowledge, experience and consulting with experts in the area, that is, the quality control department. Table 3. illustrates the root causes of the six (6) defects that have been identified in the cause-and-effect diagrams. The causes and their contribution to the problem are also calculated based on experience and product knowledge.

Table 3. Root causes and contribution of the six defects in %

Defect	Total defects	Contribution in %			
		Man	Method	Machine	Environment
High spots	0.057	25.4	0	43.9	30.7
Dents	0.155	40	0	60	0
Second paint damage	0.184	100	0	0	0
Sealer damage	0.06	39.9	0	60.1	0
Dirt	0.138	15	0	50	35
Poor fit	0.084	80	20	0	0
Other defects	0.321	35	0	50	15
Average contribution		47.9	2.86	37.7	11.52

6. Simulation Results and Discussion

6.1 Simulation results for the period before the allocation of resources for process improvement

Figure 5 and Table 4. illustrate the simulation results for the current situation; there are currently no resources allocated. The time horizon for the model is 12 months, plus 6 months for the past. This time horizon was selected to study the behaviour of the model during the past 6 months, as the data collected does not show any trends or seasonality.

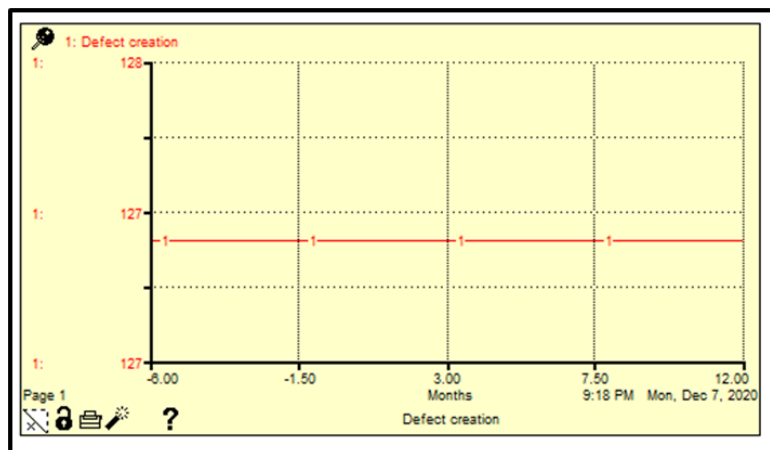
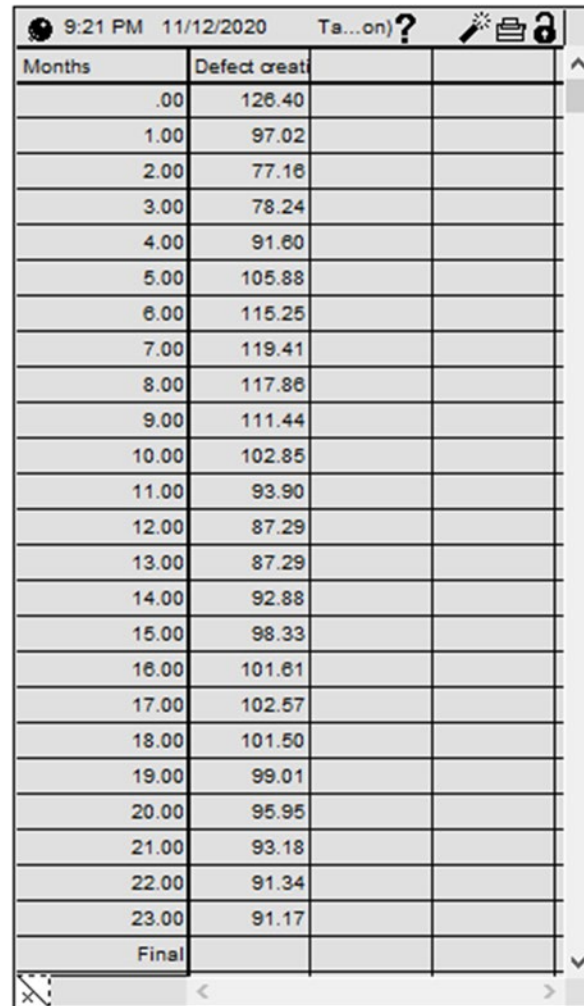


Figure 5. Simulation results for before the allocation of resources

Table 4. Simulation results for before the allocation of resources



Months	Defect creation rate		
.00	126.40		
1.00	97.02		
2.00	77.16		
3.00	78.24		
4.00	91.60		
5.00	105.88		
6.00	115.25		
7.00	119.41		
8.00	117.86		
9.00	111.44		
10.00	102.85		
11.00	93.90		
12.00	87.29		
13.00	87.29		
14.00	92.88		
15.00	98.33		
16.00	101.61		
17.00	102.57		
18.00	101.50		
19.00	99.01		
20.00	95.95		
21.00	93.18		
22.00	91.34		
23.00	91.17		
Final			

The simulation results obtained indicate that there is a constant monthly defect rate of 126 in the current situation. The defects accumulate to a total of 2284 in 18 months (12 months plus 6 months in the past).

6.2 Simulation results for the period after the allocation of resources for process improvement

Figure 6. and Table 5. illustrate the simulation results for the satisfaction level (SL) and defect creation rate after the allocation and delivery of resources for process improvement. The model time horizon is 12 months, plus 12 months in the future.

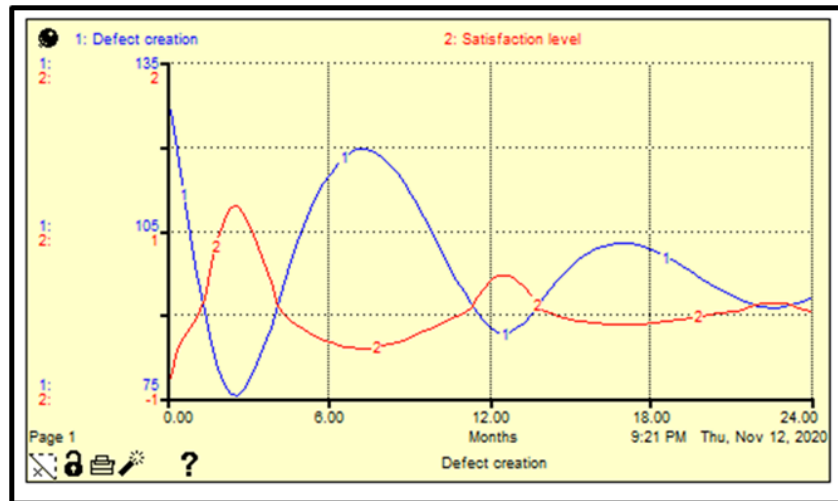


Figure 6. Simulation results for after the allocation of resources

Table 5. Simulation results for after the allocation of resources

9:21 PM 11/12/2020 Ta...on)?			
Months	Defect creati		
.00	126.40		
1.00	97.02		
2.00	77.16		
3.00	78.24		
4.00	91.60		
5.00	105.88		
6.00	115.25		
7.00	119.41		
8.00	117.86		
9.00	111.44		
10.00	102.85		
11.00	93.90		
12.00	87.29		
13.00	87.29		
14.00	92.88		
15.00	98.33		
16.00	101.61		
17.00	102.57		
18.00	101.50		
19.00	99.01		
20.00	95.95		
21.00	93.18		
22.00	91.34		
23.00	91.17		
Final			

The figure 6 shows an improvement for the future. The defect creation rate drops from 126 to 87 in 12 months, which is less than the current situation (Table 5).

6.3 Sensitivity Analysis

Figure 7. and Table 6. illustrate the simulation results for the defect creation with a sensitivity test. The simulation was carried out with a changed average delay time in the delivery of resources while all the other variables remain the same. Time delays between taking a decision and its effects on the state of the system are a reality of most systems, which delays the results.

1: 3 months

2: 6 months

3: 9 months

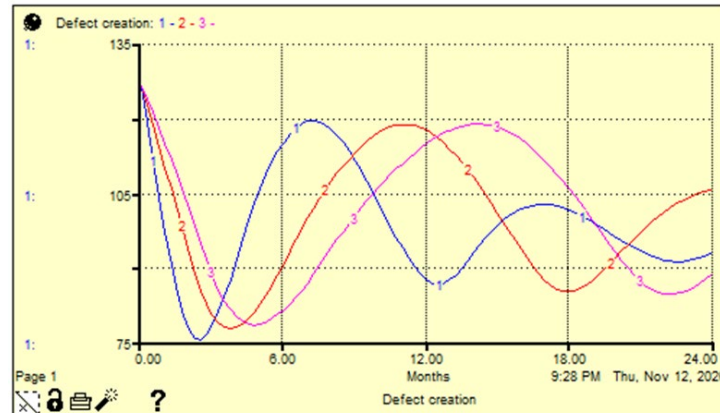


Figure 7. Sensitivity test for defect creation rate

Table 6. Sensitivity test for defect creation rate and Defect accumulation

Months	1: Defect cre	2: Defect cre	3: Defect cre
.00	126.40	126.40	126.40
1.00	97.02	109.93	114.92
2.00	77.16	92.77	101.60
3.00	78.24	80.16	88.07
4.00	91.60	77.69	79.85
5.00	105.88	82.40	78.32
6.00	115.25	90.74	81.41
7.00	119.41	99.82	86.65
8.00	117.86	107.31	93.78
9.00	111.44	113.10	100.35
10.00	102.85	117.17	106.08
11.00	93.90	118.76	110.85
12.00	87.29	117.65	114.85
13.00	87.29	113.81	117.61
14.00	92.88	108.00	118.81
15.00	98.33	100.94	118.24
16.00	101.61	93.55	115.76
17.00	102.57	87.24	111.40
18.00	101.50	85.07	105.94
19.00	99.01	87.09	99.50
20.00	95.95	91.92	92.84
21.00	93.18	96.88	87.00
22.00	91.34	100.93	84.53
23.00	91.17	103.83	85.18
Final			

Months	1: Defects	2: Defects	3: Defects
.00	0.00	0.00	0.00
1.00	115.24	120.53	122.44
2.00	203.20	224.03	232.38
3.00	279.25	311.20	328.85
4.00	361.86	389.69	413.23
5.00	459.21	468.79	492.03
6.00	568.92	553.97	571.26
7.00	686.19	648.22	654.49
8.00	805.44	750.99	743.83
9.00	921.21	860.57	840.13
10.00	1,029.56	975.38	942.70
11.00	1,128.97	1,093.35	1,050.65
12.00	1,220.08	1,211.91	1,163.05
13.00	1,306.74	1,328.33	1,279.05
14.00	1,395.93	1,440.05	1,397.23
15.00	1,491.01	1,545.47	1,515.97
16.00	1,590.76	1,643.61	1,633.43
17.00	1,692.91	1,734.63	1,747.68
18.00	1,795.22	1,820.65	1,857.14
19.00	1,895.86	1,906.16	1,960.71
20.00	1,993.73	1,994.97	2,057.70
21.00	2,088.59	2,088.80	2,148.22
22.00	2,180.99	2,187.28	2,233.96
23.00	2,272.11	2,289.40	2,318.54
Final	2,363.76	2,393.94	2,404.69

The model behaves according to expectations. An average delay time of 3 months shows improved results for defect creation compared with an average delay time of 6 months, thus reducing the defect accumulation. The same applies to the average delay time for 9 months. It can be observed that delivering the allocated resources for process improvement in months 3 and 6 reduces the defects much quicker than delivering the resources in month 9. The simulation results also indicate that a reduced delay time also results in smaller oscillations and moves towards an equilibrium more quickly. A reduced average delay time drops the defect creation rate, thus saving the organisation both time and money spend on scrapping and rework.

6.3 Proposed Improvements

Based on the identified root causes of defects and the simulation results, resources and techniques for process improvement need to be allocated. The calculated average contribution indicates that people are the main contributing source of defects, followed by machine, environment and methods. Thus, training of the organization employees is recommended. Training the workforce to the highest standards will improve product quality, employees will be able to make better and economical use of material and equipment's. this will reduce waste and lead to low cost of quality.

The simulation results also revealed that defects could be reduced through the allocation and delivery of resources for process improvement. In order to save the organisation both time and money, the delivery of resources needs to be prioritized, and the average delay time in the delivery of resources needs to be reduced as much as possible.

7. Conclusion

The purpose of this study was to identify the causes of defects and to develop a system dynamics model for studying the causalities and feedback relationships for defects that contribute to the scrapping and rework of vehicles, as well as recommend remedies for scrap and rework reduction in an automotive manufacturing company based in South Africa. The research objectives were accomplished, and the introduction of the proposed SD model can reduce defects, increase productivity and reduce overall cost. The causes of defects were identified from the company documents and the cause and effect relationships were explored using system dynamics models. The remedies for defect reduction were recommended based on the research findings and simulation results.

For future research studies, the simulation models could be a starting point for defect reduction in the automotive manufacturing industry and they can be combined with actual organisation/plant data to further refine the model. Depending on the scope of the problem being investigated, the model can be further extended to include other factors such as costing per resource for process improvement, deeper detail for the causes of defects, and sub-systems for maintenance strategies. The research study has highlighted that there are limited published papers using system dynamics (SD) as a tool for problem solving in the SA automotive manufacturing sector. More research in this area is still required as SD modelling has proven to be an excellent tool for the tracing of problems to their actual root causes, assessing a system's ability to adjust to change and to test new decisions that must be taken.

Acknowledgements

I thank Prof. John Alfred Trimble for assistance with the model and for comments that greatly improved my paper.

References

- Alefari, M., Fernández Barahona, A. And Salonitis, K. Modelling manufacturing employees' performance based on a system dynamics approach. *Procedia CIRP*, [online] 72, pp.438-443. 2018.
- Antonelli, D., Litwin, P. And Stadnicka, D. Multiple System Dynamics and Discrete Event Simulation for manufacturing system performance evaluation. *Procedia CIRP*, vol. 78, pp.178-183. , 2018.
- Azar, A., System dynamics as a useful technique for complex systems. *International Journal of Industrial and Systems Engineering*, vol 10, no. 4, p.377-2012, 2020.
- Bureš, V., *Comparative Analysis of System Dynamics Software Packages. International Review on Modelling and Simulations (IREMOS)*, vol. 8, no. 2, p.245. 2015.
- Derwisch, S. And Löwe, P. *Systems Dynamics Modelling in Industrial DEVELOPMENT EVALUATION. IDS Bulletin*, vol. 46, no. 1, pp.44-5, 2015
- Dung-Ho, T. Kumar, A And Shiwakoti, N. *Using system dynamics approach to examine the impact of ERP and Lean on manufacturing performance. Proceedings of the International Conference on Industrial Engineering and Operations Management held in Paris, France, on July 26-27, (2018).*

- En.wikipedia.org. Resource. [online] Available at: <https://en.wikipedia.org/wiki/Resource> 2020. [Accessed 26 May 2020].
- Kampa, A., Gołda, G. And Paprocka, I., *Discrete Event Simulation Method as a Tool for Improvement of Manufacturing Systems. Computers*, vol. 6, no.1, p.10. 2017.
- Sterman, J. Business Dynamics. Boston: Irwin, 2000.
- Saunders, M., Lewis, P. And Thornhill, A., *Research methods for business students. 7th ed. Harlow: Pearson*, p.569. SHARMA, P. 2020. *Discrete-Event Simulation*.
- Thompson, B. And Bank, L., *Use of system dynamics as a decision-making tool in building design and operation. Building and Environment*, vol. 45, no. 4, pp.1006-1015. 2010.
- Kcprofessional. FR , 2015. https://www.kcprofessional.fr/media/29877057/real_cost_of_re_work_from_kimberly-clark_professional.pdf [Accessed 27 Mar. 2019].
- Khakifirooz, M. Cayard, D. Chien, C And Fathi, M., A, *System Dynamic Model for Implementation of Industry 4.0: 2018 International Conference on System Science and Engineering (ICSSE)*, [online], available at: https://www.researchgate.net/publication/328762658_A_System_Dynamic_Model_for_Implementation_of_Industry_40 [Accessed 27 Jul. 2019].
- Strandhagen, J., Semini, M. And Fauske, H.,. *Applications Of Discrete-Event Simulation To Support Manufacturing Logistics Decision-Making: A Survey*2020. [online] Available at: https://www.researchgate.net/publication/221525182_Applications_of_Discrete-Event_Simulation_to_Support_Manufacturing_Logistics_Decision-Making_A_Survey [Accessed 19 March 2019].

Biographies

Shelly Mona is currently a Deputy Director at Product Development Technology Station (PDTS): Central University of Technology, Free State. She obtained a bachelor's degree in Mechanical Engineering Technology from the University of Johannesburg. She later specialized in Industrial Engineering and Management and obtained a master's degree in engineering management from Tshwane University of Technology. She holds Higher certificate in project management from University of Johannesburg, and Higher certificate in Production and Operations Management from the University of South Africa. She worked in the automotive manufacturing sector for six years, as a Product Development Engineer and Part Quality Assurance Engineer. She did her internship with the Department of Infrastructure Development, where she was doing project management under the maintenance section. She has also tutored automatic control for seven years at the University of South Africa, Department of Mechanical Engineering. She published conference papers on the Proceedings of the International Conferences on Industrial Engineering and Operations Management Pretoria / Johannesburg, South Africa, October 29 – November 1, 2018, and Detroit, Michigan, USA, August 10 - 14, 2020. She reviewed papers for 2nd Asia Pacific Conference on Industrial Engineering and Operations Management in Surakarta, Indonesia, and her research interests include: Quality management in manufacturing, advanced manufacturing technology, and application of System dynamics modelling and simulation in the manufacturing sector.