African Journal of Applied Research
Vol. 10, No. 1 (2024), pp. 547-556
http://www.ajaronline.com
http://doi.org/10.26437/ajar.30.06.2024.34

OPTIMISING LPG BOTTLING PLANT WITH DES USING FLEXSIM SIMULATION TOOL

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ABSTRACT

Purpose: This study explores the application of Discrete Event Simulation (DES) using FlexSim software to enhance the operational efficiency of a Liquefied Petroleum Gas (LPG) bottling plant. The primary goal is to ensure that the LPG plant can safely and efficiently meet escalating market demands, thereby prioritising all stakeholders' safety.

Design/Methodology/Approach: The research design focused on empirical research and experimental simulation modelling. The study began with collecting and analysing one month of LPG plant data, laying the foundation for developing a simulation model. Verification and validation processes ensured the model's accuracy, enabling the investigation of various operational scenarios. The key performance indicators like First Time to Failure (FTTF), Time Between Failures (TBF), and Time to Repair (TTR) were analysed. The availability rates were 77% from actual data and 76% from simulations, showing that the model is suitable for real-world use.

Findings: This study's findings underscore the potential impact of proactive maintenance strategies and operational enhancements as practical and applicable approaches to optimising performance. The analysis also revealed significant improvement opportunities through what-if scenarios: increasing MTBF by 100%, reducing MTTR by 50%, and raising conveyor speed by 15%.

Research Limitation: The study's dependence on a systematic literature review could restrict its ability to capture the industry's real-time dynamics.

Practical Implication: Implementing proactive maintenance strategies and operational enhancements as practical approaches can reduce downtime and costs and promote productivity and safety.

Social Implication: Optimising plant operations will help maintain supply chain stability with the growing demand for LPG.

Originality/Value: This work contributes valuable insights and recommendations, establishing a foundation for informed decision-making in the LPG bottling sector.

Keywords: *Availability. bottling plant. downtime. flexsim. liquefied petroleum gas*

ISSN: 2408-7920

INTRODUCTION

Discrete event simulation (DES) is a method used to simulate a real-world system. DES is described as an occurrence in which a physical state changes discretely at certain random time points(Qiao & Wang, 2021). Each event has a consistent time and occurs during a specific procedure. DES has traditionally been used for production and factory planning; however, in recent years, DES has been increasingly applied to manufacturing system operation applications(Budiono et al., 2021)(Prajapat et al., 2020). In the aspect of system simulation, Flexsim, an object-oriented visualised 3D modelling and simulation software, can obtain quality data by simulating the production process of products. At the same time, Flexsim has good secondary development ability and can interact with other tools (Smaili et al., 2020; Shuhai et al., 2019). The FlexSim environment is fully integrated with the C++ compiler and uses FlexScript (a pre-compiled C++ library) or C++ directly (Aliyu & Mokhtar, 2021)(Lang et al., 2021).

All the animation uses OpenGL, which features impressive virtual reality. The animation can be viewed in a tree view, 2D, 3D, and virtual reality. Two views may be seen simultaneously during the model creation or run process. Because of this, most manufacturing maintenance-related companies use FlexSim for simulations. FlexSim is a valuable tool that provides information on the dynamic flow system approach described by complexities and inconsistencies utilising DES because a system can only be enhanced if the components' interactions are understood. Hence, this technology is typically used for designing, evaluating, and optimising production systems (Cubukcuoglu et al., 2020). The significant advantage of simulation over other operational research (OR) techniques is that it allows experimentation with any element of a business system (Agalianos et al., 2020).

Liquefied petroleum gas (LPG) is a vital energy source used globally in homes, industries, and businesses (Yuniaristanto et al., 2020). As demand for LPG rises, it becomes increasingly important to ensure efficient LPG bottling plant operations to maintain a steady supply chain and meet consumer needs. The study objectives are to create a simulation model of the plant using the Flexsim DES tool, evaluate the existing processes of the LPG bottling plant, and determine any opportunities for optimising its operations and maximum safety (Bariha et al., 2022).

RESEARCH METHODOLOGY

The research design focuses on empirical research and experimental simulation modelling. The project started with gathering and examining plant data and then creating a model utilising the FlexSim DES simulation tool. FlexSim is the primary tool for building the simulation model, enabling scenario testing, optimisation, and performance analysis. The model was then verified and validated to ensure its precision and consistency before being implemented to investigate multiple scenarios and assess possible outcomes. Subsequently, the data was analysed to identify trends and patterns, providing valuable decision-making insight.

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Data Collection and Analysis

Data on plants was gathered and examined for the study over one month. Since the factory was closed on Sunday, this amounted to 24 operating days. The facility was operational from 7 a.m. to 11 p.m. every working day (16 operating hours). The gathered data served as the foundation for the one-day production modelling employed to replicate the performance of a one-day production. Data-collecting techniques were carried out methodically and thoroughly to guarantee that the model-creation process was accurate and representative. The actual plant architecture in an AutoCAD drawing, the time capacity report for the daily production data from the Divert module, and the interrupt report for the time of failure and duration of downtime for the Carousel system are among the data gathered.

FINDINGS AND DISCUSSION

Building The Flexsim Simulation Model

The task of the simulation is to reproduce the considered production process. Therefore, it has become necessary to model the entire simulation system correctly (Krynke, 2021). The simulation model was built using the AutoCAD layout plan of the actual LPG plant's Flexspeed production unit, as shown in Figures 1 and 2.

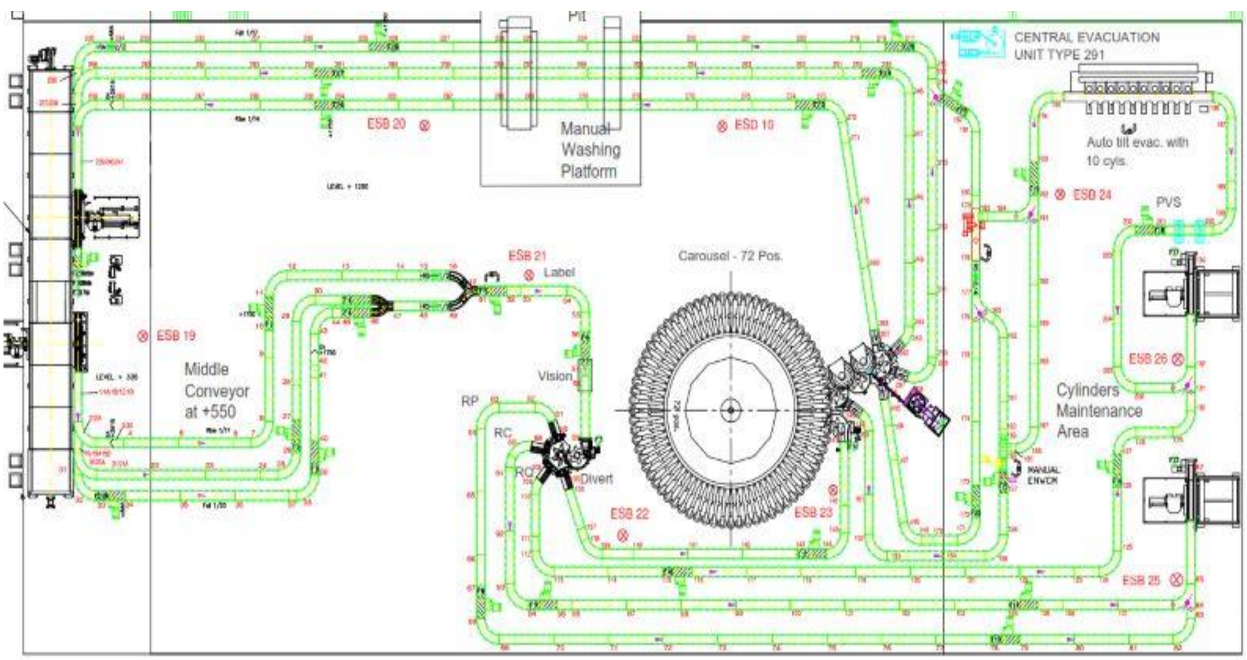

Figure 1. The LPG AutoCAD layout plan of the Flexspeed unit.

ISSN: 2408-7920

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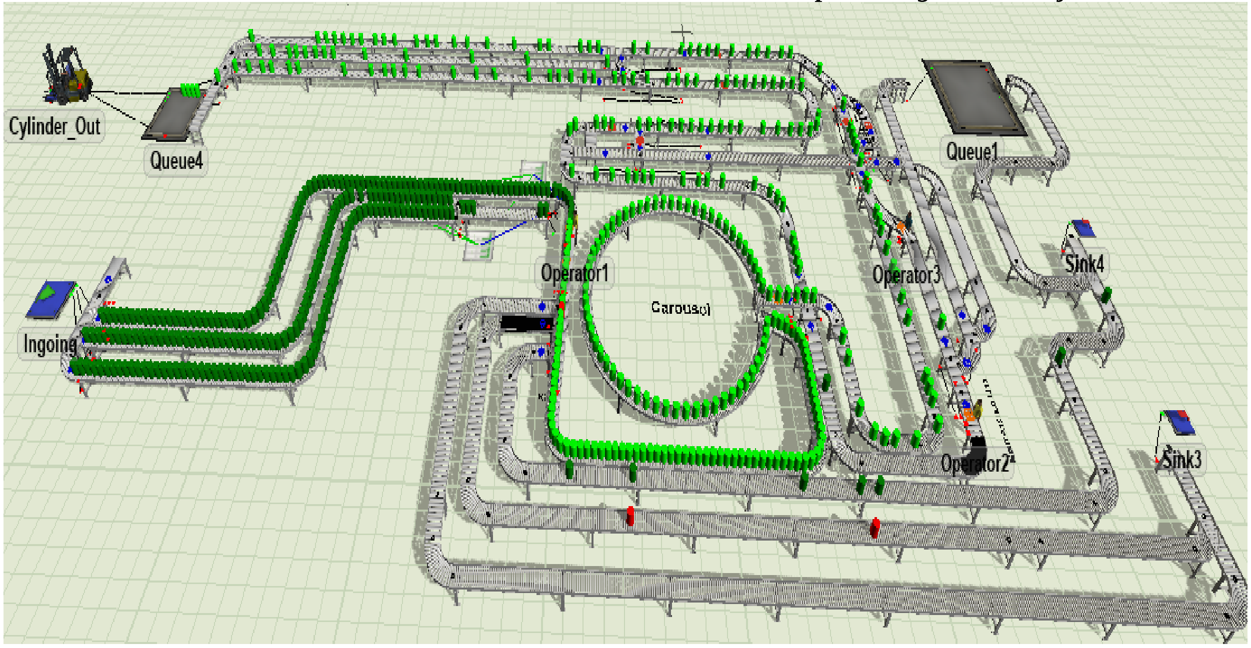

Figure 2. The developed Simulation Model.

Plant Performance Data

The plant time capacity report found crucial information about the plant's utilisation trends and operational performance. The average daily performance was calculated by gathering and analysing report data spanning 24 days. The report presents the results of the inspection and sorting station, which classify the entering cylinder condition into four groups: 1) qualified (OK), 2) requalified (RQ), 3) reconditioned (RC), and 4) painted (RP). The cylinder is marked "OK" if it has met all criteria and "RQ" if it hasn't passed the testing and periodic inspection. "RC" denotes a need for repair and rework measures to be taken on these cylinders, some of which include a safety relief valve, fill valve, and float gauge. “RP” is assigned for the cylinders that must be repainted to meet the standard.

Table I. Daily Output Average.

Daily Output Average				
DAY	OK	RQ	RC	RP
1	26249	249	216	2460
2	26900	361	126	3405
3	27483	259	209	2621
4	27317	362	177	2513
6	3233	352	417	3973
7	1054	107	43	1105
8	13480	141	113	2545
9	28478	314	77	3173
10	23489	218	74	2797

ISSN: 2408-7920

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http://doi.org/10.26437/ajar.30.06.2024.34

11	26499	268	210	2535
13	31149	386	196	3781
14	28374	244	191	1835
15	31606	308	160	1549
16	26814	296	180	1921
17	27906	223	122	1463
18	26919	315	140	2486
20	31716	284	348	2514
21	26702	270	181	2151
22	22935	308	202	1958
23	27300	279	200	2078
24	24758	237	129	1662
25	26775	268	290	1761
27	15642	158	108	1176
28	30476	315	224	1884
Average	**24302**	**272**	**181**	**2306**
Total				**27061**

The report offers in-depth details of the system's disruptions, including the moment the system fails (failure start time) and when it starts working again (failure end time) (Tsarouhas, 2020 ; Patel, 2021)This data may generate critical metrics like time to first failure (TTFF), time between failure (TBF), and time to repair (TTR) that are required to compute availability and run the Flexsim model.

The average conveyor speed in the LPG plant ranges from 15 to 30 meters per minute (0.2 to 0.5 m/s), with the facility's actual average speed being 0.37 m/s (Monk Conveyors Limited, 2020)(Maznan & Chee Kiong, 2021)The conveyor speed and operating time are required to develop the Flexsim model, specifically for material handling operations. The LPG facility is open from 7 a.m. to 11 p.m. every day for 16 hours.

Failure and Downtime Model

Statistical software (Weibull++) was used to model the TTFT, TBF, and TTR data to test the assumption that the data were random. Before being modelled, all the time values were transformed to seconds to be compatible with the time inputs in the Flexsim model. The results of the Weibull++ distribution analysis is shown in Table 2.

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Table 2: Weibull++ distribution analysis

Results Report A (TTFT)	
Report Type	Plot Results
User Info	
Name	Bello Gada
Company	LPG
Date	2/14/2024
Parameters	
Distribution	Exponential 1P
Analysis	RRX
CB Method	FM
Ranking	MED
Mean Time (sec)	8588.5093
LK Value	-243.5802
Rho	-0.876478
Fail \ Susp	24 \ 0

Results Report B (TBF)	
Report Type	Weibull++ Results
User Info	
Name	Bello Gada
Company	LPG
Date	2/14/2024
Parameters	
Distribution	Exponential 1P
Analysis	RRX
CB Method	FM
Ranking	MED
Mean Time (sec)	6133.1847
LK Value	-1651.375
Rho	-0.89305
Fail \ Susp	168 \ 0

Results Report C (TTR)	
Report Type	Weibull++ Results
User Info	
Name	Bello Gada
Company	LPG
Date	3/17/2024
Parameters	
Distribution	Exponential 1P
Analysis	RRX
CB Method	FM
Ranking	MED
Mean Time (sec)	2046.7376
LK Value	-1437.697
Rho	-0.975304
Fail \ Susp	168 \ 0

The statistical analysis parameter, regression of coefficient (Rho), and probability plotting revealed that the Exponential (1 parameter) distribution is capable of modelling all the data. Table 3 displays the exponential distribution parameter and corresponding Rho value for every data group.

Table 3: MTFF, MTBF, MTTR values.

Parameter	Measure	sec	Rho
Mean Time to First Failure	MTTFF	8589	0.88
Mean Time Between Failure	MTBF	6133	0.89
Mean Time to Repair	MTTR	2047	0.97

Plant Output and Availability

Based on the capacity report, the daily average and percentage of OK, RQ, RC, and RP cylinders were computed and are shown in Table 4.

Table 4: Daily average output.

OK	RQ	RC	RP	Total
24302	272	181	2306	27061
89.81%	1.00%	0.67%	8.52%	100%

The availability is the proportion of the overall running time of machinery or other equipment to the total machine time available. The machine runs efficiently during the operating time, which reduces the loading time with downtime (i.e., interruptions, adjustments, breakdowns, and other stops).

$$Availability = \frac{Total\ time - Downtime}{Total\ time}$$

The following summarises the number of failures and downtime based on one-month data.

•Total failures over the recorded period: 169 times

•Total failure time: 18065 minutes

•Total downtime: 5379 minutes

The data indicates that 169 failures were recorded each month. These failures resulted in 5379 total downtimes or 224 minutes daily. Using the preceding calculation for a 16-hour (960-minute) workday, the plant's average availability for a single day is computed to be 0.77, or 77%.

Flexsim Simulation and Validation

The results from the Weibull++ distribution analysis show the first time to failure is 8589 seconds, downtime is 2069, the uptime is 5394, was run into the Flexsim simulation model, and the result from the Carousel's breakdown time simulation is 14028.11 minutes. Based on the simulation results, the availability of breakdown time is 14028.11 seconds. Breakdown = 14028.11 seconds ≈ 234 minutes, Total time is 16 hours = 960 minutes.

$$Availability = \frac{960-234}{960} = \frac{726}{960} = 0.76$$

$$Availability = 76\%.$$

The simulation results are tabulated in Table 5, as well as the actual plant data.

Table 5: Daily average output

	Actual	Simulation	Delta	Error %
Ingoing	27061	26647	-414	-1.53
OK	24302	23994	-308	-1.26
RC	181	165	-16	-8.8
RQ	272	283	11	4.04
RP	2306	2205	-101	4.37
Breakdown	224 m	233.8 m	-9.8	-4.37
Availability	77%	76%		

The model is validated by comparing the actual availability with simulation results. The exact and simulation availability was 77% and 76%, respectively, indicating a negligible difference in the Flexspeed incoming process. This validates the model for simulating the proposed improvement scenarios.

When actual production output is compared to simulation results, there is only a small amount of fluctuation, with errors for each component—aside from RC—being less than 5%. This research shows how well and consistently the simulation model captures real-world situations. By contrasting the simulation findings with the confirmed availability, the Flexsim model is verified. There was a 1% discrepancy between the simulated and actual availability, which were 77% and 76%, respectively. Rajakarunakaran et al. (2015) support the finding that the outcome validates the model by showing that it can accurately depict the architecture and operations of the actual facility.

Applying The Proposed Strategies

To assess possible plant performance improvement in terms of availability, three improvement scenarios are considered for simulation:

- Case I: Increase MTBF by 100%
- Case II: Reduce MTTR by 50%
- Case III: Increase Conveyor speed by 15% (maximum speed).

All three cases were simulated, one after another, and the results are shown in Table 6.

Table 6: Availability for each improvement scenario simulation

Case	Scenario	Availability (%)
I	Increase MTBF by 100%	83%
II	Reduce MTTR by 50%	88%
III	Increase Conveyor speed by 15%	76%

The simulation findings showed that a longer time interval between failures enhanced system availability from 76% to 83%. This was determined by analysing the effects of increased uptime (MTBF), decreased downtime (MTTR), and higher conveyor speed on system availability. Furthermore, availability increased from 76% to 88% when downtime was cut in half. When implemented, these strategies can significantly enhance the LPG plant's capacity to safely and efficiently meet escalating market demands, thereby demonstrating the potential benefits of this research in industrial engineering and LPG production. The findings support the study of Bechtsis et al. (2018) that concluded conveyor speed increases; however, they did not have an appreciable impact on system availability. Considering the 83% and 88% improvements in instances I and II, respectively, more research was conducted on cases I and II to observe the impact by modelling the combined parameters in Flexsim as case IV. Table 7, displays the remarkable 91% increase in availability that the simulation produced.

Table 7: Availability for combining cases I and II

Case	Scenario	Availability (%)
IV	Combine Case I and II	91%

CONCLUSION

The Flexsim Discrete Event Simulation (DES) model is an effective tool for simulating complex processes. It has proven to be highly dependable and accurate, with an error rate of less than 2%. This tool has been instrumental in identifying opportunities to improve the bottling process for liquefied petroleum gas (LPG), allowing plant availability to increase by an impressive 15%, from 76% to 91%.

ISSN: 2408-7920

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http://doi.org/10.26437/ajar.30.06.2024.34

In addition, the DES analysis has also provided invaluable insights into the LPG bottling process, enabling a better understanding of areas that require improvement to enhance efficiency and productivity. By implementing the recommendations from this analysis, the LPG bottling plant can achieve greater operational efficiency, improve supply chain stability, and meet the growing demand for LPG while ensuring safety, reliability, and compliance with industry standards. The resulting recommendations were practical, pertinent, and in line with the constraints of the LPG bottling plant. As such, this study is a valuable resource for informing decision-making processes.

Recommendation

The following recommendations are made.

- To improve plant performance, it is recommended that strategies be prioritised that will increase equipment reliability (MTBF). This can be achieved through proactive maintenance schedules, equipment upgrades, or process enhancements that minimise wear and tear on critical components. Extending MTBF by 100% could enhance the plant's availability by 7% resulting in significant gains in operational productivity.
- It is also important to focus on reducing the downtime MTTR to enhance system availability. This can be achieved through streamlined maintenance procedures, better access to spare parts, or training programs to strengthen maintenance staff efficiency. By minimising repair times and reducing downtime by 50%, the system availability can be significantly increased by 12%.
- To optimize plant availability, a combined strategy that capitalises on the benefits of increased MTBF and decreased MTTR is advised. Improving uptime while reducing downtime can significantly enhance the plant's overall availability. Our simulations demonstrate that augmenting MTBF by 100% and reducing MTTR by 50% can achieve an impressive availability rate of 91%, an increase of 15%.

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ISSN: 2408-7920

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