A PROJECT REPORT

On

Operations Modelling and System Dynamics Simulation

Submitted to

University of Liverpool

Operations Modelling and Simulation (EBUS504)

BY **CHRISTINA ANN JACOB (201805307)**

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Executive Summary

This report is divided into two important sections: Operations Modeling and System Dynamics, both applied to solve real problems using simulations.

The first involves the Operations Modeling of the manufacturing system by applying Witness Horizon. The bottlenecks of the process flow are fixed, resulting in the rise of productions from 468 to 832 units. The cost per unit fell from \$127 down to \$109.Changes like adding inspection tasks to the assembly process, better part sequencing, and using a conveyor system made the system faster and smoother. Bottleneck analysis showed machines worked better, delays reduced, and everything was more aligned. The optimized system handled variability well and is ready for future growth.The second part focuses on System Dynamics, where we used Vensim software to study how fishing activities, fish populations, and profits are connected. The interrelationship between them was shown with a Causal Loop Diagram; then, simulations over 10 years tested different policies: taxes, restrictions on fishing, and management of older ships. Each policy had its pros and cons, but the results showed that the limitation of fleet growth and restriction of fishing methods were the most effective in controlling overfishing and protecting the ecosystem.
This report shows how simulations can help us make better decisions, improve efficiency, and balance economic growth with sustainability.

Part 1: Operation modelling

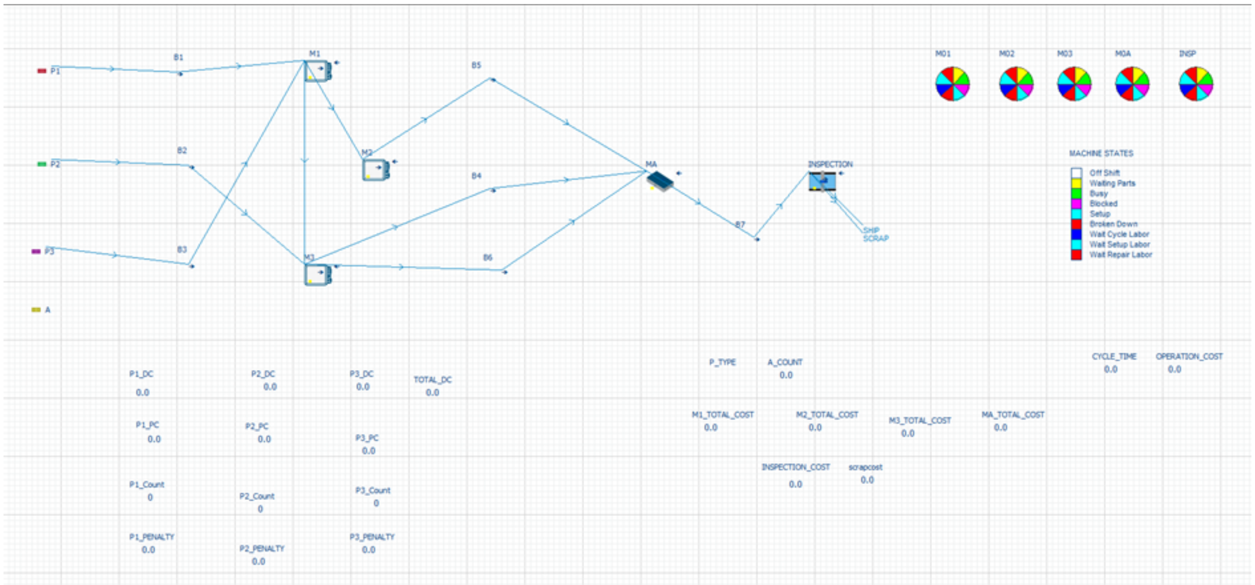


Fig 1 : NormalSimulation witness model

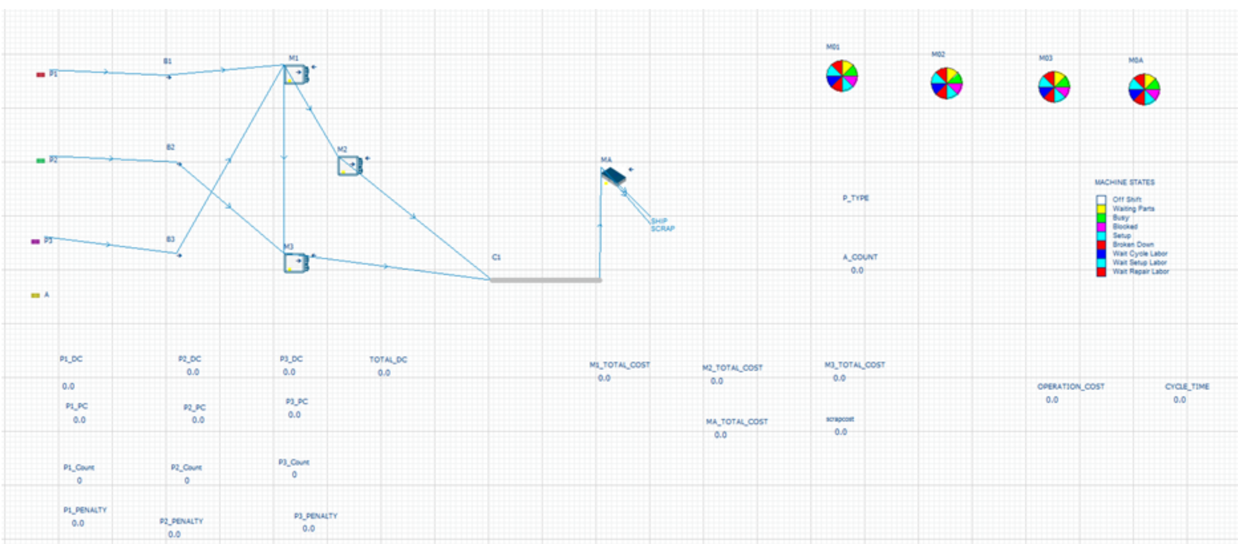


Fig 2: Model after optimization

This optimized model made some really useful changes that boosted both efficiency and output. Production jumped from 468 units to 832 units, and while the total cost increased from $59,461.7

to $90,985, the cost per unit dropped from about $127 to $109. So, even though we're spending more, it's actually more cost-efficient.

Key enhancements included integrating the role of the inspection station into the MA.By integrating the 5-minute inspection into MA, products are shipped or scrapped right after assembly without additional steps, hence reducing costs. This integration smoothed the work flow and utilized the idle time of MA while maintaining the 1% scrap rate to ensure quality control without additional infrastructure.

Another improvement was changing how MA worked. Before, it followed a strict sequence, waiting for 2 P1 parts, 2 P2, and 1 P3, which caused delays. Now, MA takes whatever parts are ready first but still completes the final requirement of 2 P1, 2 P2, and 1 P3. This made things faster, reduced idle time, and freed up space on the floor for other uses. Machine cycle times were also reduced, enabling faster processing of parts.This made certain that a constant supply of parts was available to the assembly with little or no queues and bottle-necks.

The conveyor system would link the machines M1, M2, and M3 directly to MA. It means the parts could wait on the conveyor system as the MA attended to other jobs in the queue while it maintained the flow of the parts without idling the machines; this increased the system throughput very significantly, utilizing the resources effectively.

These optimizations have amazing results: production went up by 77.8%, from 468 to 832 units. While costs increased, the system became way more efficient by reducing delays and making better use of resources. This shows how fixing bottlenecks and improving workflows can really improve output without wasting money or space.

Bottleneck analysis

Bottleneck analysis before and after system optimization shows that large changes in system performance are observed, which was due to major limiting constraints in the throughput. Before optimization, the main bottleneck was Machine 3, M03, with an extremely high utilization rate of 99.987%. This shows that M03 was fully utilized and hence slowed down the entire system. The inspection station is also not efficient: parts are waiting 98.450% of the time while it is busy only 1.550%. This caused further delays downstream, creating another minor bottleneck. In contrast, the assembly machine had the lowest utilization-31.20%-while it waited for 68.800% of its time. This imbalance showed poor coordination between the processes, resulting in inefficiencies.

Name	Sector	Value	Percentage
M01	Waiting Parts	0.000	0.000
	Busy	68.787	68.787
	Blocked	31.213	31.213
	Setup	0.000	0.000
	Broken Down	0.000	0.000
	Wait Cycle Labor	0.000	0.000
	Wait Setup Labor	0.000	0.000
	Wait Repair Labor	0.000	0.000
M02	Waiting Parts	37.493	37.493
	Busy	62.507	62.507
	Blocked	0.000	0.000
	Setup	0.000	0.000
	Broken Down	0.000	0.000
	Wait Cycle Labor	0.000	0.000
	Wait Setup Labor	0.000	0.000
	Wait Repair Labor	0.000	0.000
M03	Waiting Parts	0.013	0.013
	Busy	99.987	99.987
	Blocked	0.000	0.000
	Setup	0.000	0.000
	Broken Down	0.000	0.000
	Wait Cycle Labor	0.000	0.000
	Wait Setup Labor	0.000	0.000
	Wait Repair Labor	0.000	0.000
M0A	Waiting Parts	68.800	68.800
	Busy	31.200	31.200
	Blocked	0.000	0.000
	Setup	0.000	0.000
	Broken Down	0.000	0.000
	Wait Cycle Labor	0.000	0.000
	Wait Setup Labor	0.000	0.000
	Wait Repair Labor	0.000	0.000
INSP	Waiting Parts	98.450	98.450
	Busy	1.550	1.550
	Blocked	0.000	0.000
	Setup	0.000	0.000
	Broken Down	0.000	0.000
	Wait Cycle Labor	0.000	0.000

Fig 3 : Machine states before optimization

In the improved model, the system exhibits several changes: the utilization of M03 decreased to 77.838%, showing that it is not as tightly bottlenecking as before; this can be achieved by redistributing the load to introduce a conveyor system in order to manage the flow of the parts. The utilization of the assembly machine increased to 83.207%, showing better coordination and sequencing of tasks. Inclusion of inspection tasks directly into MA , eliminating a stand-alone inspection station avoided the delay that may be caused by unnecessary movement of products. Machines 1 and 2, showed improved task flow with reduced idle times. M01's blocking is now slightly reduced to 33.282%, and M02 increased to 44.453%, thus better aligned with the downstream processes. This shows how effective addressing the bottleneck at M03 and improving flow to MA really was.

In contrast, M02 shows an increased waiting time of 55.547% over the pre-optimized model performance because its capacity is now greater than the downstream consumption rates, thus queueing the parts to be processed by M03 and MA.

Conveying system and higher emphasis on MA and M03 eliminated the downstream bottlenecks, but slightly unsynchronized M02 capacity with respect to the rest of the system. While M02 waits more, the overall improvement of the system throughput from 468 units to 832 units shows that the changes were effective.This additional wait time is cheap because it shows the scalability of the system, and it prioritizes the downstream processes, M03 and MA, for maximum throughput.

Name	Sector	Value	Percentage
M01	Waiting Parts	0.000	0.000
	Busy	66.718	66.718
	Blocked	33.282	33.282
	Setup	0.000	0.000
	Broken Down	0.000	0.000
	Wait Cycle Labor	0.000	0.000
	Wait Setup Labor	0.000	0.000
	Wait Repair Labor	0.000	0.000
M02	Waiting Parts	55.547	55.547
	Busy	44.453	44.453
	Blocked	0.000	0.000
	Setup	0.000	0.000
	Broken Down	0.000	0.000
	Wait Cycle Labor	0.000	0.000
	Wait Setup Labor	0.000	0.000
	Wait Repair Labor	0.000	0.000
M03	Waiting Parts	0.000	0.000
	Busy	77.838	77.838
	Blocked	22.162	22.162
	Setup	0.000	0.000
	Broken Down	0.000	0.000
	Wait Cycle Labor	0.000	0.000
	Wait Setup Labor	0.000	0.000
	Wait Repair Labor	0.000	0.000
M0A	Waiting Parts	16.793	16.793
	Busy	83.207	83.207
	Blocked	0.000	0.000
	Setup	0.000	0.000
	Broken Down	0.000	0.000
	Wait Cycle Labor	0.000	0.000
	Wait Setup Labor	0.000	0.000
	Wait Repair Labor	0.000	0.000

Fig 3 : Machine states after optimization

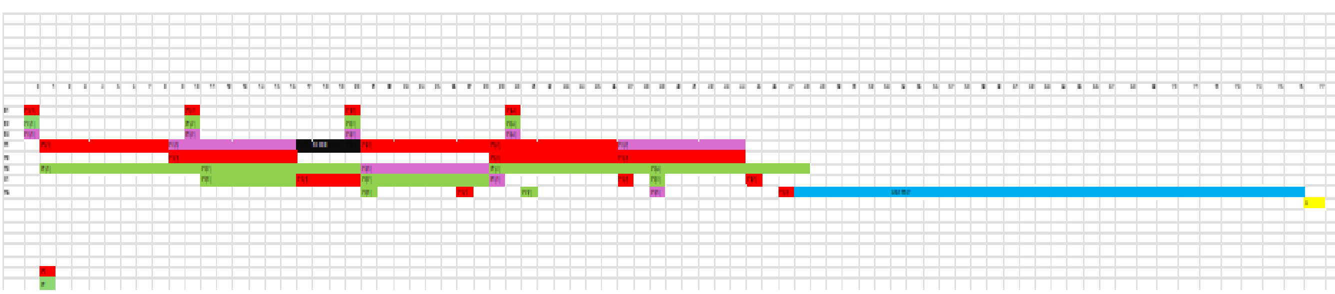


Fig 4: *Gantt Chart After Optimization*

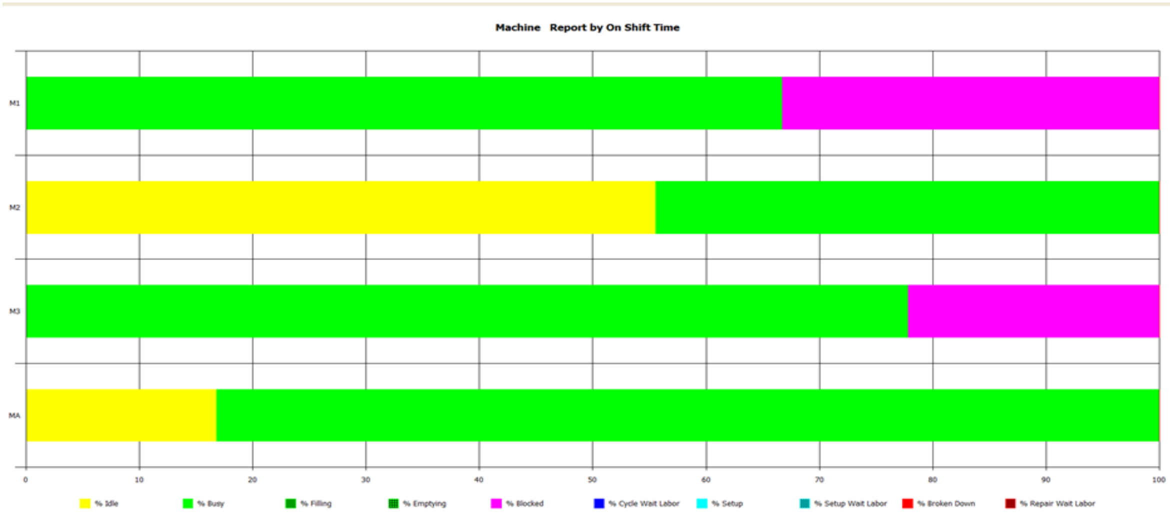
The Gantt chart provides a timeline view of the activities across machines and processes. By analyzing the chart:

M03’s constant operation is evident, with no significant idle or waiting periods. This indicates it is the bottleneck, as it stalls upstream and downstream processes.**Other machines (M01, M02, and MA)** have visible idle times, showing underutilization caused by the bottleneck at M03. For example:**MA (Assembly Machine)** is idle while waiting for parts from M03, highlighted in the chart by gaps in its activity.**Inspection Station and Conveyor** show delays as they await parts processed by M03.

Utilization Efficiency=(Busy Time/Total Time)×100
M03 Before Optimization: 99.987/100=99.987%
M03 After Optimization: 77.838/100=77.838%

MA's utilization increased from 31.20% to 83.207%, which directly contributed to higher throughput and reduced delays. The improvement indicates that task sequencing has been done in a more appropriate manner, and redundant inspection tasks have been eliminated.
Optimized system: 832 units vs. initial model: 468 units. Overall costs went up but the per unit cost came down from about $127/unit to $109/unit, showing improved efficiency.

Before optimization, M03 had no idle time, but MA and M02 experienced long waits. After optimization, M03 was blocked 22.162% of the time, showing better alignment with MA. MA’s waiting time reduced to 16.793%, indicating smoother operation.

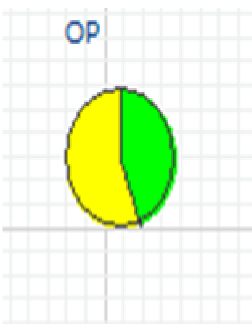


By addressing the bottleneck at M03, redistributing workloads, and integrating inspection into MA, the system became more balanced. The results include higher throughput, better resource utilization, reduced idle times, and a more cost-effective and stable operation.

Analysis of Optimal Minimum Number of Operators

Introducing a single operator to handle the setup tasks for Machines M1, M2, and M3 doesn't change the overall output of the system, which remains at 832 units.The setup time for each part is fixed at 2 minutes, no matter the part type.The operator's busy time is 44.447%, while idle time accounts for 55.553%.

From the operator's report, the operator spends 44.447% of the time working, while the remaining 55.553% is idle. This shows that one operator can easily manage all setup tasks in the 30,000-minute simulation time, with plenty of idle time left. The operator completed 6,668 jobs, with an average job time of 2 minutes, which is the exact setup time required per part.



Name	Sector	Value	Percentage
OP	Busy	44.447	44.447
	Idle	55.553	55.553

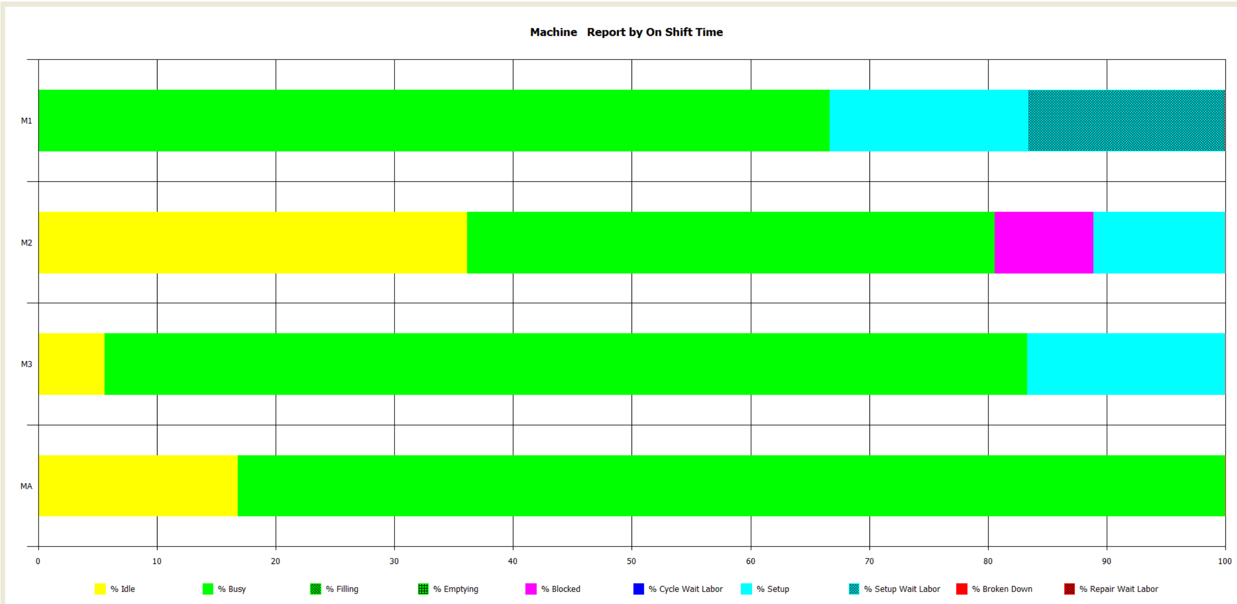
The setup tasks are distributed efficiently across the machines, as shown in the machine state data:

- M1: Setup accounts for 16.667% of its time.
- M2: Setup accounts for 11.113% of its time.
- M3: Setup accounts for 16.667% of its time. These percentages show that setup tasks are well-aligned with each machine's workload, ensuring no bottlenecks or delays.

Despite the additional setup requirement, all machines maintain high utilization rates:

- M1: 66.667% busy.
- M2: 44.427% busy.

- M3: 77.753% busy. The absence of significant blocked or idle times validates that the operator's schedule aligns with the machine cycle times, preventing disruptions in part processing.



The following calculations and observations confirm why one operator is sufficient:

1. Total Setup Time Requirement: Each part processed by the machines requires 2 minutes of setup time. The total parts processed by each machine are:
   - M1: P1(1,664)+P3(832)=2,496 parts
   - M2: P1(1,664)=1,664 parts
   - M3: P3(832)=832 parts. The total setup time across all machines is:

Total Setup Time=2×(2,496+1,664+832)=9,984 minutes
Since the operator has 30,000 minutes available and only needs 9,984 minutes for setup, there's plenty of time for other tasks or variations in workload. The operator is busy 44.447% of the time and has 55.553% idle time, which confirms that one operator can handle the setup tasks without issue. The remaining 55.553% idle time ensures that the operator has the capacity to accommodate variations in part flow or workload.The introduction of the setup time does not affect machine throughput:M03, the most utilized machine, operates at 77.753% busy time with

no blocked states.MA continues to process parts efficiently, ensuring the system achieves the desired output of 832 units.

Adding more operators would result in underutilization and higher costs without improving system performance. The operator's idle time of 55.553% confirms there is sufficient capacity to handle all setup tasks with one operator.

Steady State Analysis of the model:

How the System Handles 20% Variation:

The model was tested with ±20% changes in supplier delivery rates (uniform distribution), machine setup times, and inspection station cycle times (triangular distributions). The simulation ran for 10,000 minutes with a time cell size of 60 minutes.

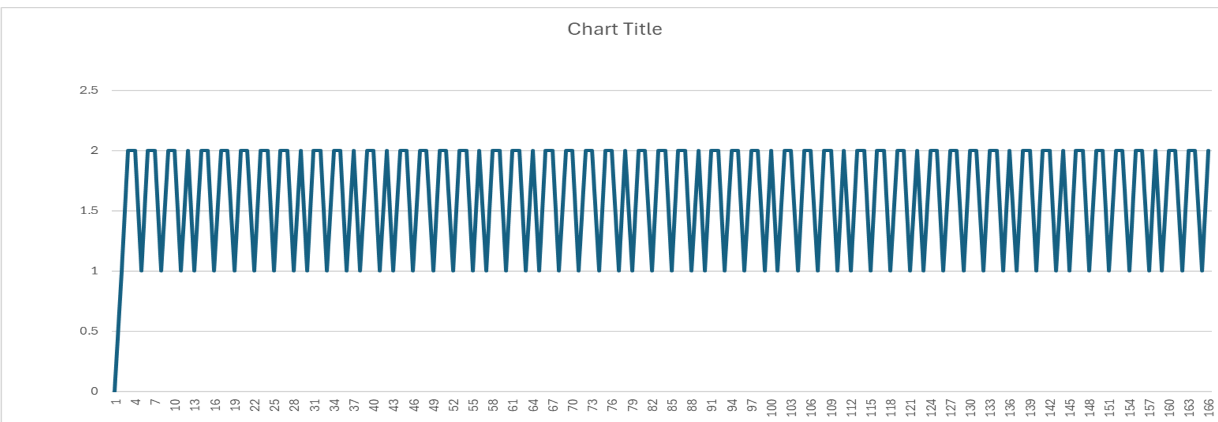


Figure 5: *Production Per Hour Graph*

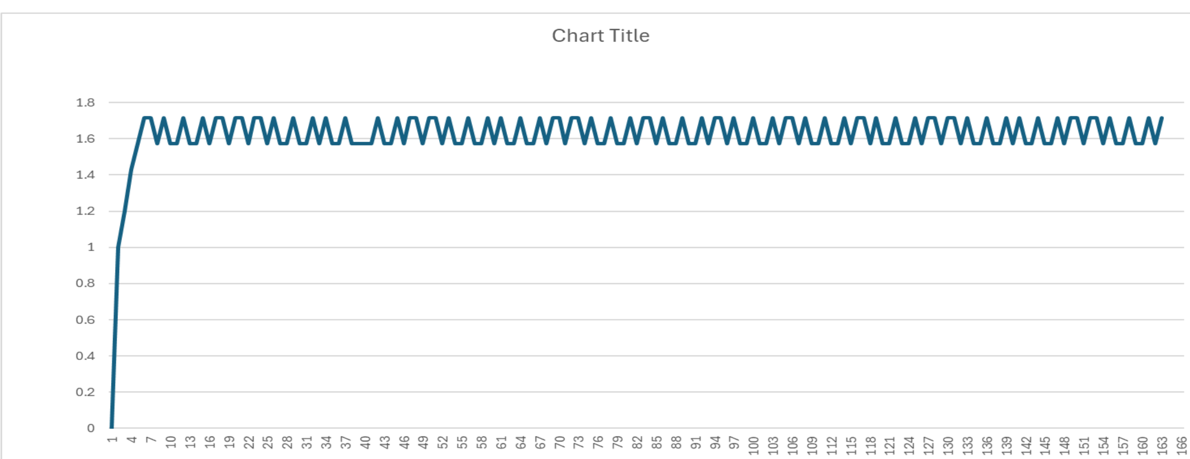


Figure 6: *Welsh Moving Average Graph*

The production per hour graph (Figure 5) shows large changes during the early phase but becomes steady after around 6 time steps (~360 minutes). The Welsh smoothing graph (Figure 6) confirms the system reaches steady-state, though small fluctuations remain, showing it's working near its limits with this variability.

The system's throughput reduced slightly from 832 units to 817 units, showing that it can handle some variability but is still affected by disruptions. Despite this, the optimized system performed well under ±20% variability, showing the success of the changes made to the procurement plan and processes.Delivery costs went up slightly from **$17,160 to $17,490**, showing that the system is sensitive to changes in supply rates.**M02** emerged as the bottleneck during this test. It had more waiting parts and was less busy than usual, causing a bit of a slowdown.Despite this, **M03 and MA** remained steady, keeping the system running smoothly.

.How the System Handles 30% Variation:

The model was tested with ±30% changes in supplier delivery rates (uniform distribution), machine setup times, and inspection station cycle times (triangular distributions). The simulation ran for 10,000 minutes with a time cell size of 60 minutes.

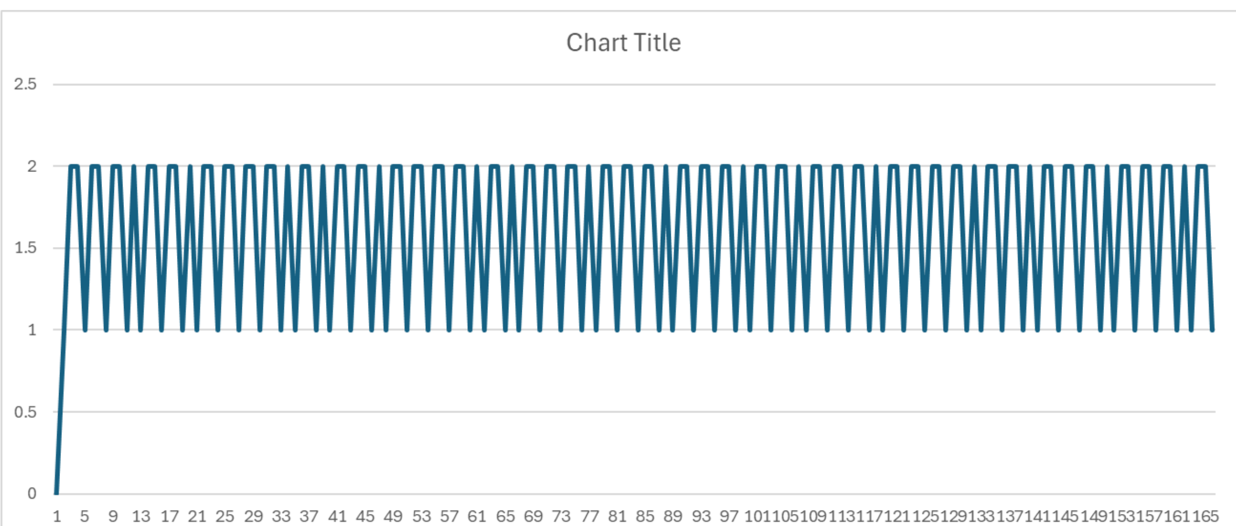


Figure 7: *Production Per Hour Graph*

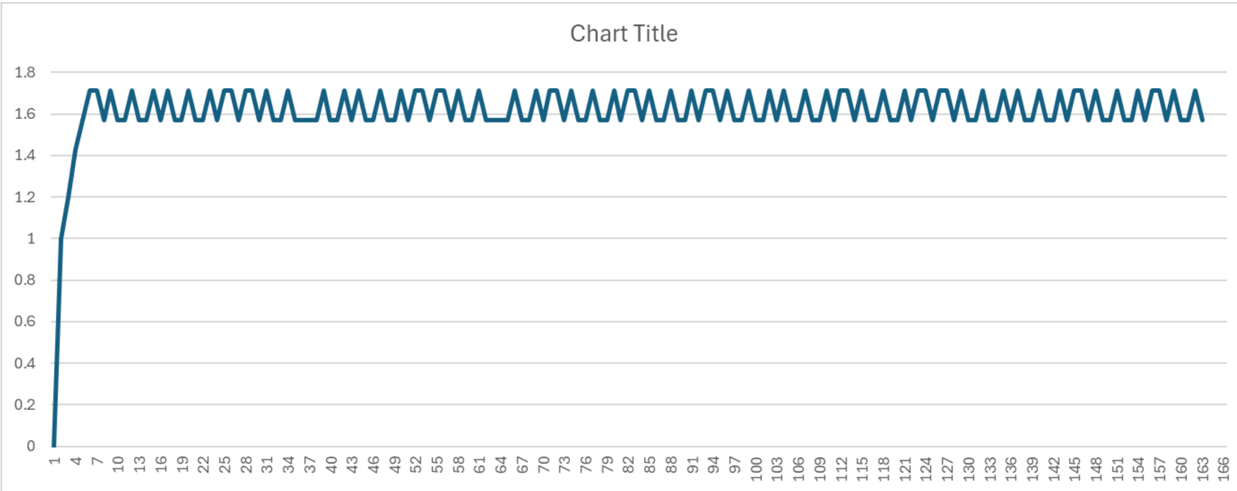


Figure 8: *Welsh Moving Average Graph*

The production per hour graph (Figure 7) shows significant changes during the early phase but becomes steady after around 6 time steps (~360 minutes). The Welsh smoothing graph (Figure 8) confirmed that the system could stabilize, but the fluctuations were more noticeable, showing that the system was under higher stress.

The system's throughput dropped slightly from 832 units to 815 units, showing that while the system remains stable, the increased variability slightly affects performance. This shows that while the system can handle variability, higher levels of variation affect its performance more.However, the optimized system still performed well overall, maintaining efficient operations under challenging conditions.Delivery costs stayed steady at **$17,490**, which means financial impacts were still manageable even under these conditions.**M02** was again the bottleneck, with more waiting parts and less busy time. This confirms that M02 struggles the most under variability.Meanwhile, **M03 and MA** held steady, ensuring the system kept running smoothly despite the disruptions.

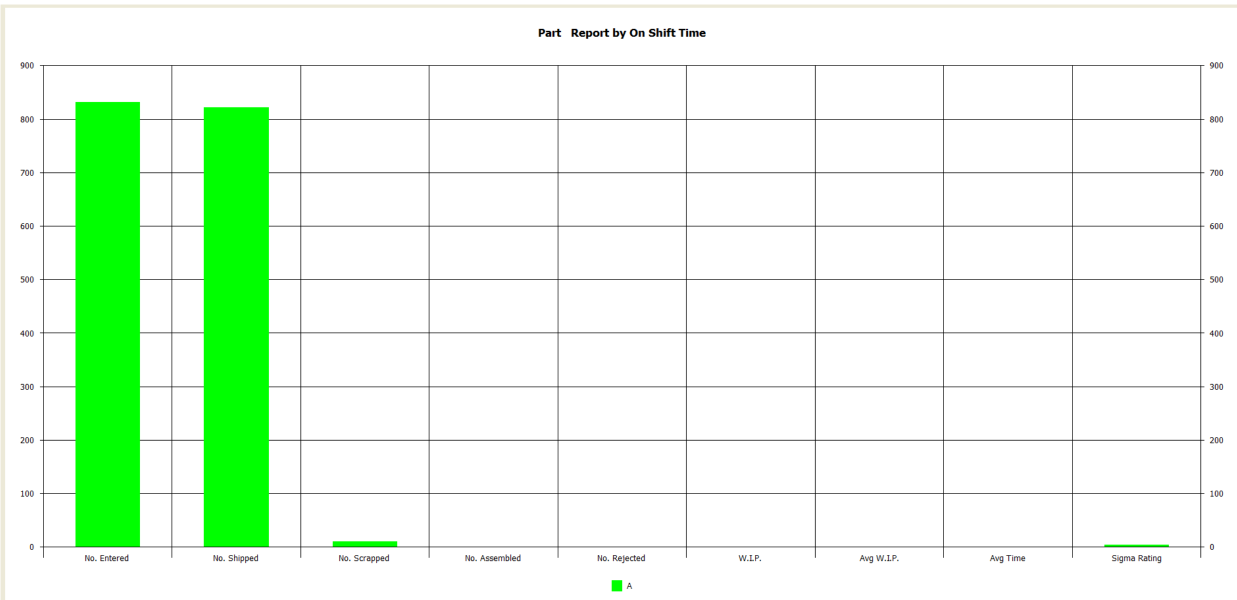
Minimizing the Impact of 30% Variation

Statistics Report Report by On Shift Time

Labor

Name	% Busy	% Idle	Quantity	No. Of Jobs Started	No. Of Jobs Ended	No. Of Jobs Now	No. Of Jobs Pre-empt...	Avg Job Time
OPERAT...	22.271	77.729	2	6673.000	6671.000	2	0	2.003

Figure 9 : Labor Statistics Report Showing Operator Efficiency

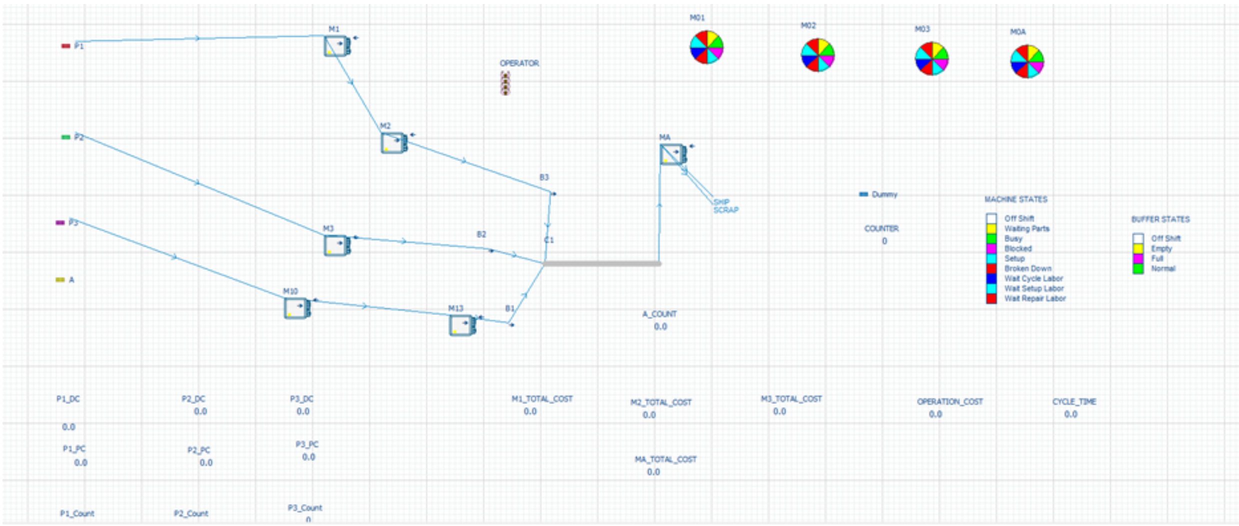


To deal with the 30% variability in delivery, setup, and inspection times, I added a second operator to the system. This change brought the production back to 832 units, just like before the variability.

With two operators, the system handled delays much better. M01's busy time improved a bit to 66.72%, and its blocked time dropped to 13.69%. M02 also performed better, with waiting time going down to 34.73%, though blocked time increased slightly to 9.60%—probably due to material flow issues. M03 stayed steady with a busy time of 77.81%, and the assembly machine (MA) kept its high busy time of 83.20%.

Adding the extra operator really helped reduce waiting times and kept things moving smoothly despite the variability. Sure, it added some cost, but the system's performance was back on track.

Critical Analysis of the First Solution with Supporting Evidence



In this setup, extra machines were added for P1 and P3, buffers were used to keep things running smoothly, and four workers managed setups and moving parts around. These changes increased production to 1,302 units almost double the original goal showing the system can handle a lot more demand.

Pros

- ➢ Producing 1,302 units shows the system can handle more demand. Adding duplicate machines for P1 and P3 allowed parallel processing, reducing the load on bottleneck machines like M03. Studies confirm parallel processing is great for increasing throughput. (Imseitif & Tang, 2019).
- ➢ Buffers helped prevent delays by breaking up machine dependencies and keeping the workflow running smoothly. Studies back up that buffers can reduce delays in manufacturing.(Hedvall et al., 2017).
- ➢ With four operators managing setups and movements, idle times were minimized.
- ➢ Having duplicate machines made the system more reliable. Even if there were supply chain problems or setup time changes, things could keep running without big issues.

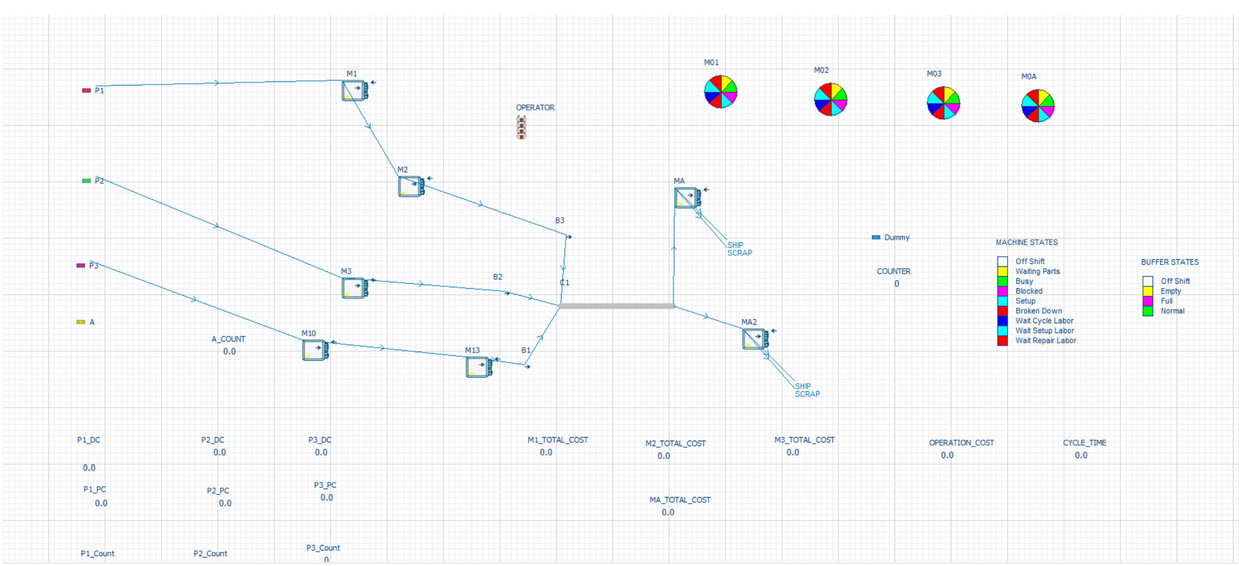
Cons

- ➢ Buying extra machines wasn’t cheap. It’s a big expense, especially for smaller businesses. Studies show equipment duplication significantly increases costs (Imseitif & Tang, 2019).
- ➢ Managing more machines and buffers made the system more complicated. Poor coordination could lead to confusion and inefficiency.(Hedvall et al., 2017).
- ➢ Extra machines use more energy and require more maintenance. Research on sustainable manufacturing shows how these kinds of expansions can affect costs and the environment.(Rosen & Kishawy, 2012).

Real-Life Implications

This setup works best for industries with steady, high demand. It’s flexible and can grow, but it’s pricey, so it’s not great for businesses with seasonal or changing workloads. The extra machines use more energy, which isn’t great for sustainability. Using energy-efficient tech could help, but that costs more too. Plus, depending on workers for setups and moving parts keeps things organized but comes with risks like absences or needing to train people regularly.

Critical Analysis of the Second Solution with Supporting Evidence



In this solution, a second assembly machine (MA) was added to the setup used in the first solution, which already included duplicate machines for P1 and P3, buffers, and four operators.

Pros

- ➢ Production output increased to 1,871 units, reflecting a 43.7% improvement over the first solution. Adding the second assembly machine fixed the bottleneck at MA, speeding up production and making it more consistent. Research shows that fixing bottlenecks boosts production.(Imseitif & Tang, 2019).
- ➢ With two assembly machines running at the same time, the upstream machines faced less pressure, leading to smoother workflows and better material flow.Studies show that working with machines at the same time helps reduce delays and makes the process run more smoothly.(Hedvall et al., 2017).
  Adding another assembly machine made the system more reliable by having a backup in placeThis solution meets the current demand for more production and also sets the system up for future growth. Research confirms that adding parallel machines helps systems handle more work without needing major changes.(Amjath et al., 2023).

Cons

- ➢ Adding another assembly machine requires a significant financial outlay. The cost of high-tech assembly machines can be a barrier for facilities with limited budgets (Imseitif & Tang, 2019).
- ➢ - More machines and buffers need extra space, which might not work in every factory. This can be an issue for businesses with limited room (Hedvall et al., 2017).
- ➢ Operating two assembly machines doubles energy consumption and increases maintenance needs. Research on sustainable manufacturing emphasizes the environmental and financial costs of increased energy use (Rosen & Kishawy, 2012).
- ➢ Managing work between two assembly machines is more complex, especially if upstream processes vary. Poor load balancing can lead to delays or machines not being used efficiently (Amjath et al., 2023)

Real-Life Implications

This setup works well for industries with steady, high demand, like automotive or electronics.For industries with changing demand, the high cost might not be justified. When things are slow, having too much capacity can mean higher costs without enough money coming in. Using more energy and needing extra maintenance can be bad for the environment. To fix that, it's important to use energy-efficient technology, but it costs more. The second assembly machine makes it easier to grow in the future without big changes, so it's a good choice for long-term growth.

Comparison with First Solution

While the first solution achieved 1,302 units, this solution achieved 1,871 units, showcasing its superior ability to handle high demand. However, the additional investment, space, and operational costs make it suitable primarily for industries with stable, high production requirements.

Part 2: System Dynamics

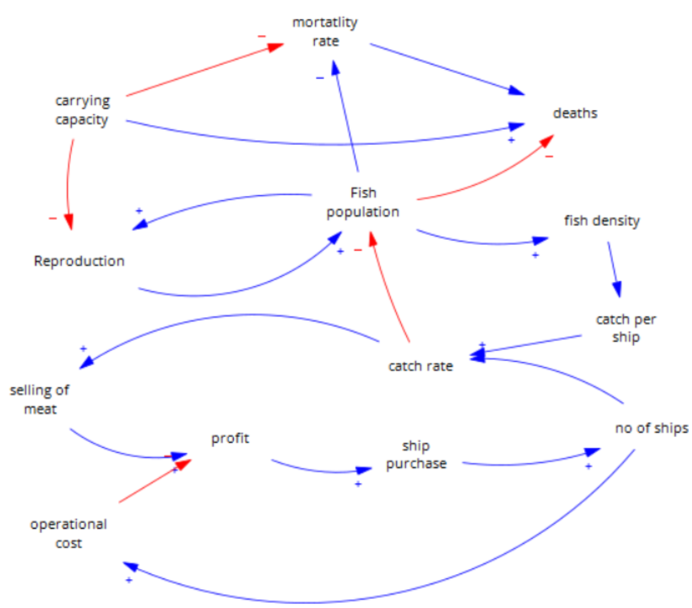


Fig 10: Casual loop diagram

The causal loop diagram shows how the fish population, fishing activities, and profits are interconnected. It highlights the need for balance between ecological sustainability and economic growth.The fish population grows through reproduction but is limited by the carrying capacity (1,200 fish). Mortality increases as the population approaches this limit. Overfishing reduces fish density, slowing reproduction and increasing the risk of collapse.

Fish Population Growth=Reproduction−Deaths−Catch Rate

Catch Rate=Number of Ships×Catch per Ship

Profit=(Total Catch×20)−(Number of Ships×250)

Reinforcing Loops: Higher profits lead to more ships, increasing the catch rate and profits in the short term. However, this increases fishing pressure, reducing the fish population and fish density, which harms the industry over time.

Balancing Loops: The fish population is naturally balanced by carrying capacity and mortality. Operational costs also balance profits, limiting how much the fishing industry can grow.

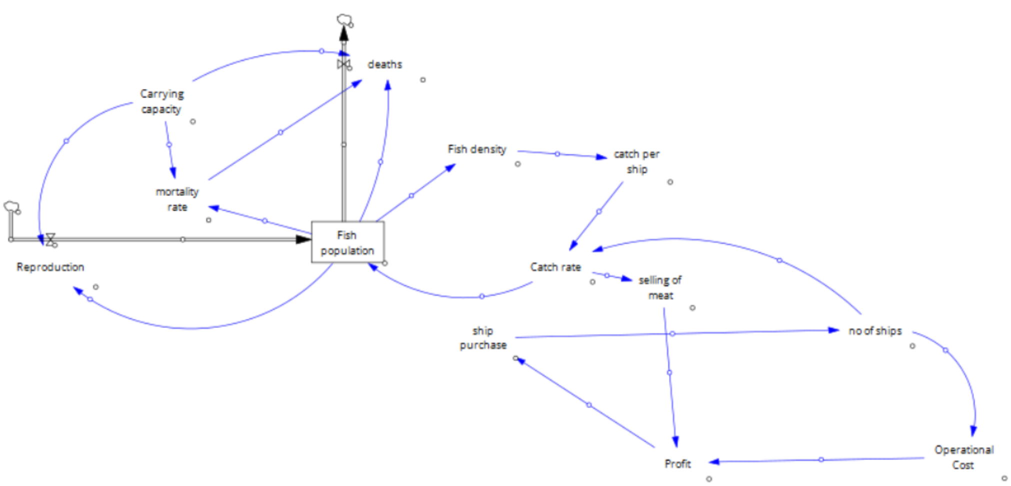
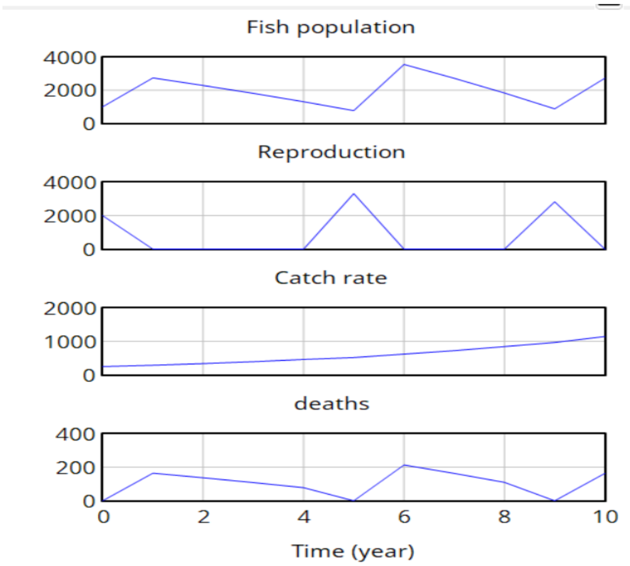


Fig 11 : Vensim model



Critical Analysis of System Behavior Over 10 Years

The simulation shows how the fish population, fishing activities, and profits are connected and affect each other over time.

Years 0 to 2: Rapid Growth and Overconfidence
At first, the fish population grows quickly, jumping from 1,000 to 2,750 because reproduction is much higher than mortality. Fish density peaks at 27.5, making it easier for ships to catch fish. This increases catch rates (250 to 396.9) and profits. With higher profits, the fleet expands from 10 to 13.6 ships.The high reproduction and profits make it seem like the fish population is unlimited. But this rapid growth hides the risk of overfishing as the population nears its carrying capacity.

Years 3 to 5: Population Collapse
By Year 3, the fish population exceeds its natural limit, and mortality rates spike. Overfishing speeds up the decline, with the population dropping sharply from 2,293 to 767.8 by Year 5. Fish density and catch rates fall drastically, and profits begin to suffer, even though the fleet reaches its peak size (21.6 ships).This period shows the damaging effects of overfishing. The industry

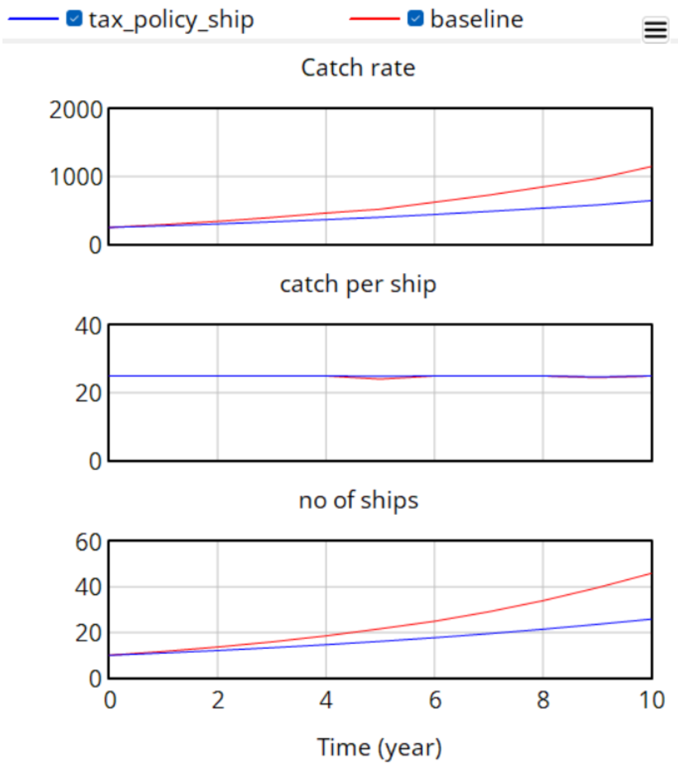
doesn’t respond to the warning signs of declining fish density, leading to a collapse that harms both the ecosystem and the economy.

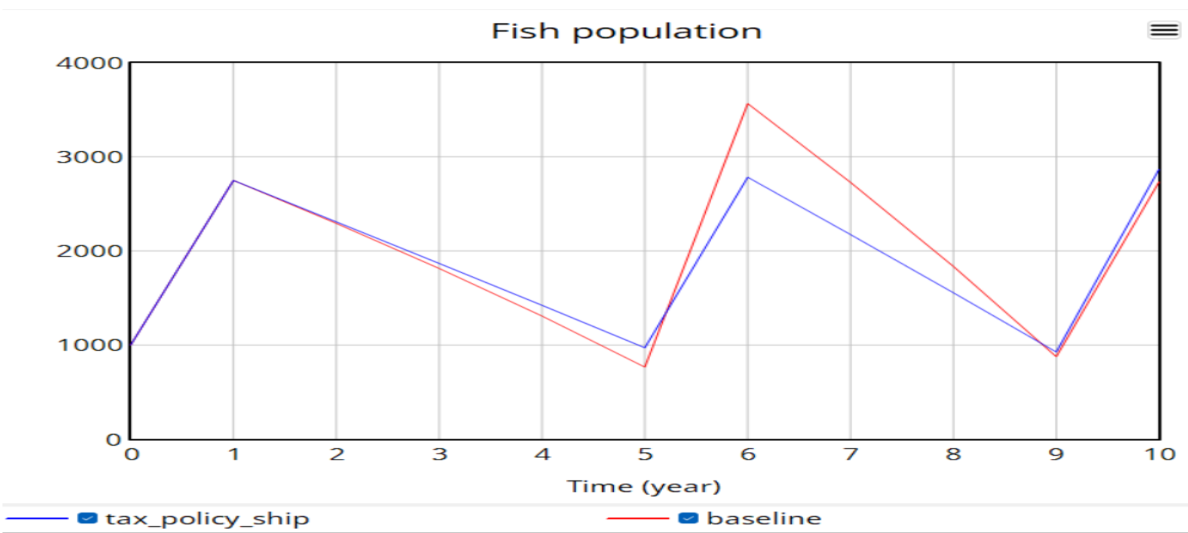
Years 6 to 10: Slow Recovery with Challenges

After the collapse, the fish population starts to recover slowly, reaching 2,735 by Year 10. Fish density improves from 7.67 to 27.3, which helps catch rates and profits go up again. But the recovery is delicate, as there are still a lot of ships (7.66 by Year 10), which puts pressure on the ecosystem. The recovery happens because fish are now reproducing faster than they’re dying.
After the collapse, the fish population starts to recover slowly, reaching 2,735 by Year 10. Fish density improves from 7.67 to 27.3, which helps catch rates and profits go up again. But the recovery is delicate, as there are still a lot of ships (7.66 by Year 10), which puts pressure on the ecosystem. The recovery happens because fish are now reproducing faster than they’re dying
However, the industry’s focus on profits and fleet growth keeps the system vulnerable to another collapse.
Reinforcing Loops: High fish density drives profits, leading to more ships and overfishing. This loop causes the population to collapse when it dominates the system.Balancing Loops: Mortality and carrying capacity stabilize the population. Recovery happens when more fish are born than are dying, but only if fishing pressure is reduced. The simulation shows how overfishing can quickly wipe out the fish population and profits. Even when the population starts recovering, the same focus on making money can easily cause the same problems again. To protect the fishery, we need sustainable policies, like controlling the number of ships or how much fish can be caught.

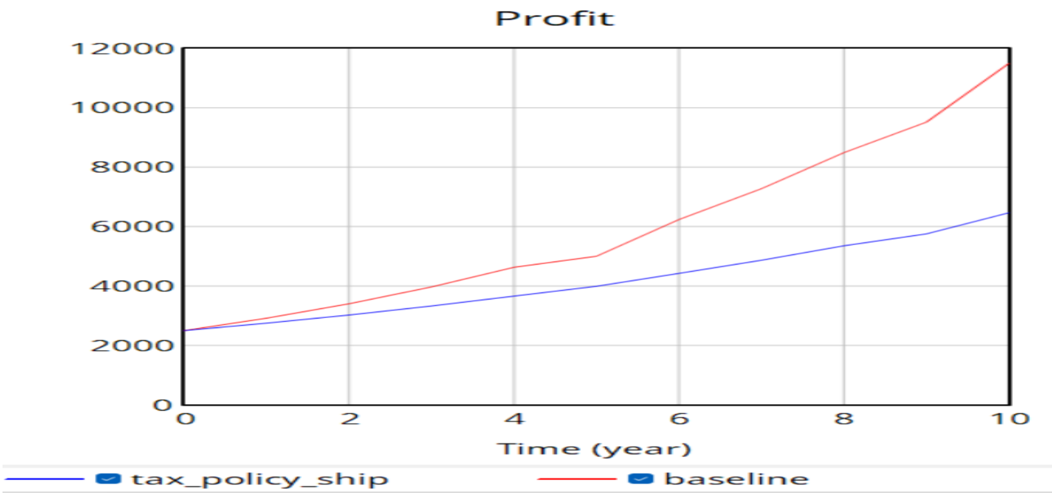
Analysis of Tax Policy on New Ships

The high tax on new ships ($200 per ship) really slows down the growth of the fleet compared to the baseline. By Year 10, the fleet is only 17.7 ships with the tax, while it’s 24.9 ships without it. Because there are fewer ships, the catch rate drops to 646.6 in Year 10, compared to 1,149 in the baseline. Fewer ships means less pressure on the fish population.





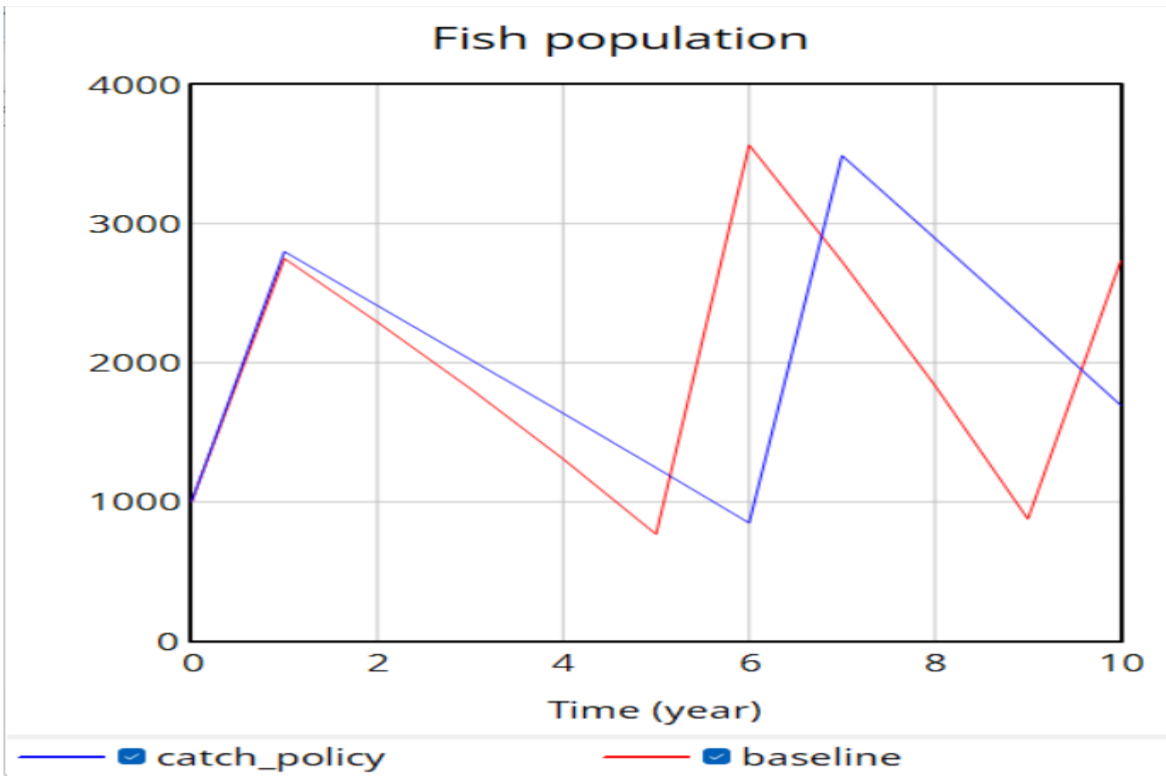
Because of the tax, the fish population recovers quicker and stays healthier. By Year 10, it grows to 2,869.6, compared to 2,735.3 in the baseline. Fish density also gets better, reaching 28.7 by Year 10 with the tax, while it recovers slower in the baseline. With less fishing, the fish population can stabilize and grow naturally.



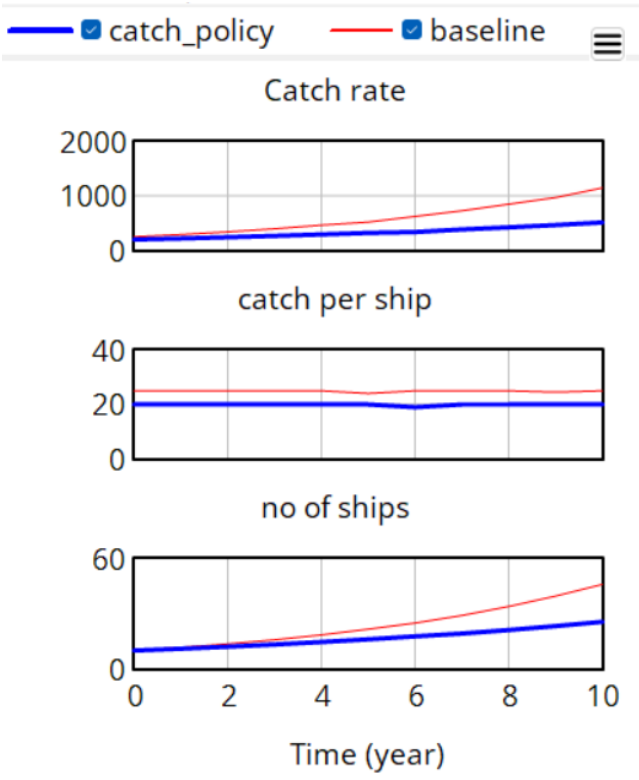
Even though there are fewer ships, profits under the tax are still good, reaching $6,465.6 by Year 10. It's a bit less than the baseline's $11,490.5, but the fish population is in better shape. Operational costs are also lower because the fleet is smaller. The tax reduces the cycle where profits push for more ships, keeping a better balance between making money and protecting the environment.

Critical Analysis of Policy to Prohibit Specific Fishing Methods

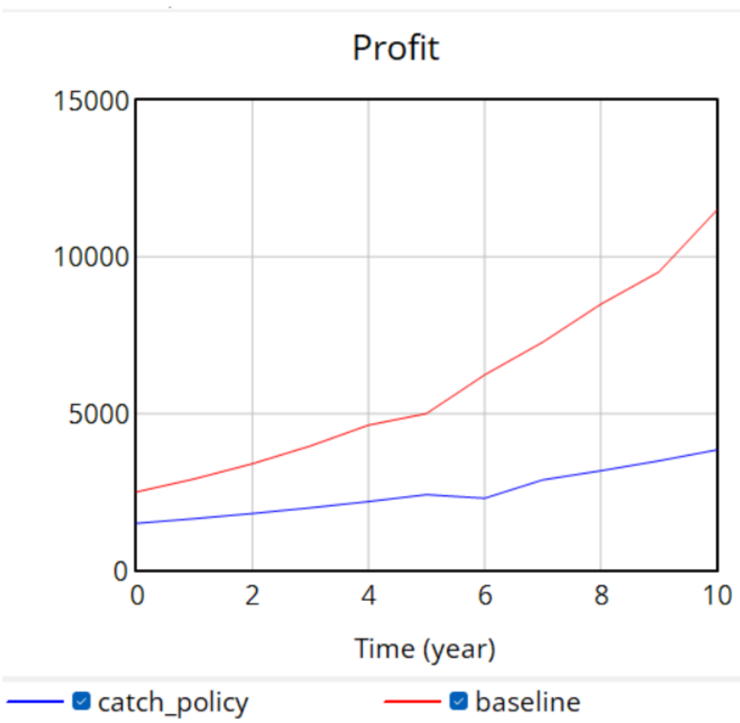
The policy prohibiting specific fishing methods directly reduces the efficiency of fishing, leading to slower catch rates per ship. This change impacts the fish population, profits, and fleet expansion. Here's a concise analysis of its effectiveness compared to the baseline model:



The fish population is better protected at first, hitting 2,800 in Year 1 compared to 2,750 in the baseline. But by Year 10, it drops to 1,694.68, which is way lower than the baseline of 2,735.28. This policy slows the initial decline in the fish population, but the long-term trend indicates that the reduced catch efficiency alone is insufficient to prevent overfishing.



With this policy, catch rates are much lower, reaching only 512.43 by Year 10, compared to 1,149.05 in the baseline. Because fishing is less efficient, fewer fish are caught,which slows down the cycle of profits leading to overfishing.



Profits are substantially lower under the policy, starting at $1,500 compared to $2,500 in the baseline. By Year 10, profits only reach $3,843.27, far below the baseline's $11,490.50. Slower catch rates and less efficient fishing methods mean profits grow much slower, which could make it hard to get the industry to follow the policy.

The fleet size grows more moderately under the policy, as lower profits slow the reinvestment in new ships. This limits overall fishing pressure compared to the baseline.
By limiting fleet growth indirectly, the policy supports the ecosystem's recovery. Banning certain fishing methods does slow down overfishing and helps the fish population, but on its own, it's not enough to keep things stable in the long term.

Analysis of Dry Dock Policy for Older Ships

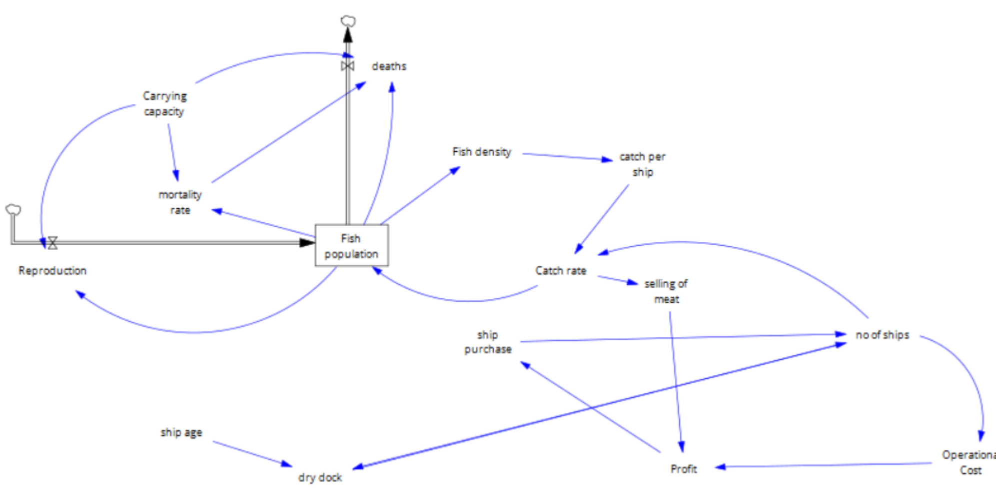
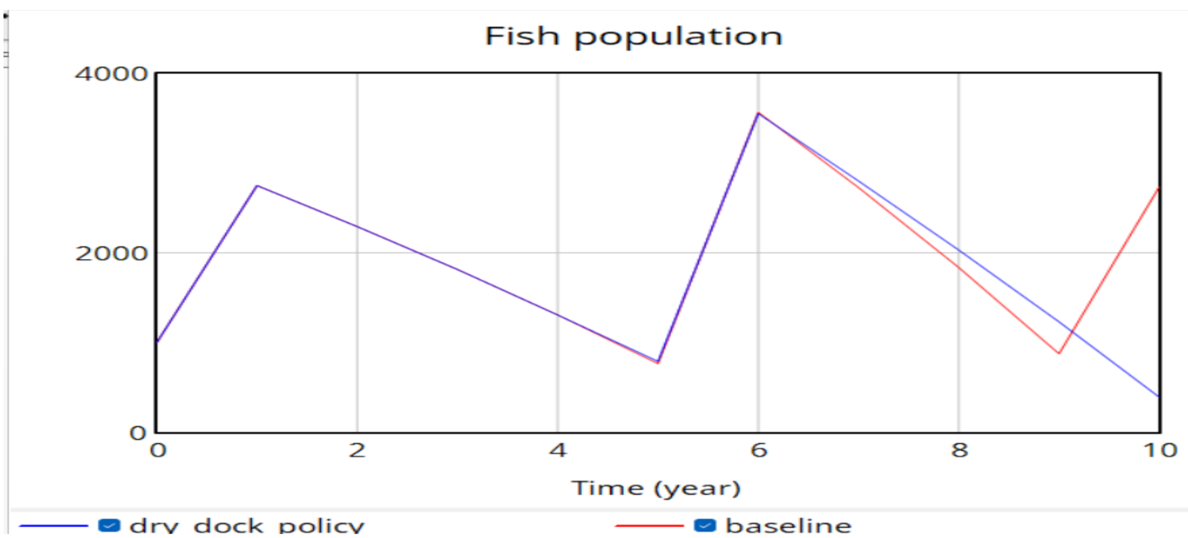


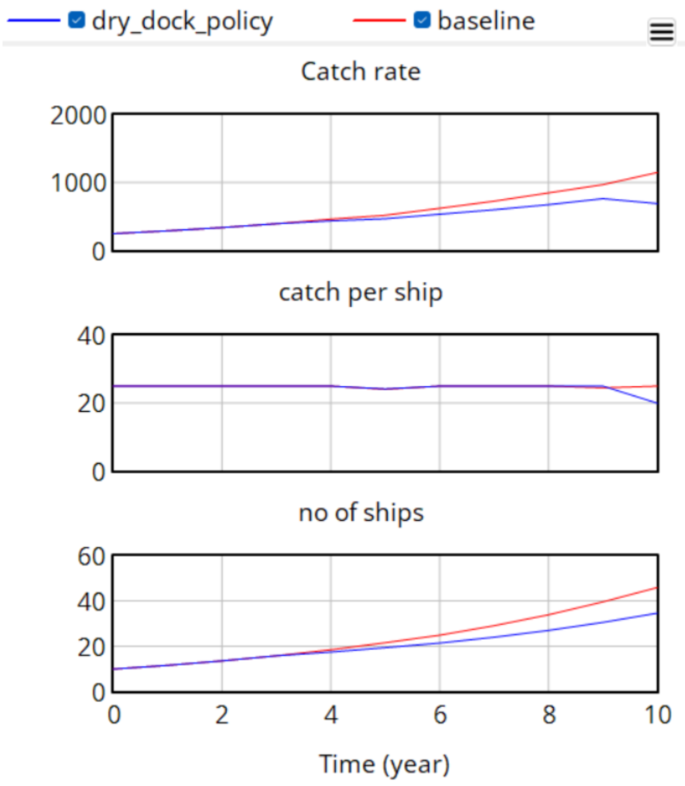
Fig 12 : Vensim model

Time (year)	0	1	2	3	4	5	6	7	8	9	10
dry dock : dry_dock_policy	0	0	0	1	1	1	1	1	1	1	1
dry dock : baseline											
ship age : dry_dock_policy	10	11	12	13	14	15	16	17	18	19	20
ship age : baseline											

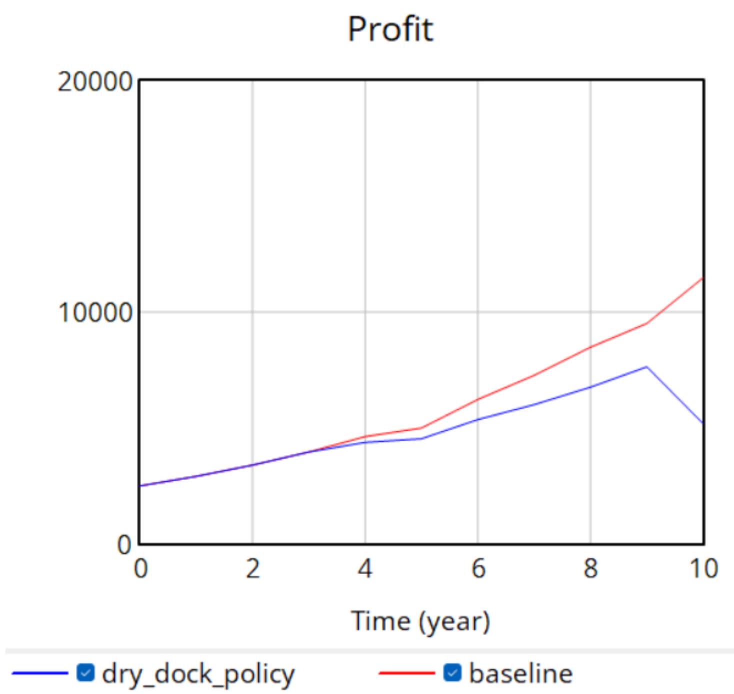
The dry dock policy, which removes ships older than 12 years, has a significant impact on fleet growth, fishing pressure, and profits while promoting ecological sustainability. The fish population declines more sharply under the dry dock policy, reaching 394.99 in Year 10 compared to 2,735.28 in the baseline. Fish density also ends up much lower, at 3.95 in Year 10 versus 27.35 in the baseline. While the policy helps slow down overfishing, it doesn't fully stop the steep decline in fish stocks, showing the need for extra measures to protect them.



Fleet size grows slower under the policy, reaching **34.66 ships** in Year 10 compared to **45.96 ships** in the baseline. Catch rates also remain lower, peaking at **692.81** compared to **1,149.05** in the baseline.The policy reduces fishing pressure by limiting fleet growth and catch rates, weakening the reinforcing loop of overfishing.



Profits drop significantly under the policy, reaching **$5,189.43** in Year 10 compared to **$11,490.50** in the baseline. Operational costs are reduced due to a smaller fleet.The policy achieves economic sustainability by reducing costs but sacrifices profitability, requiring further optimization to balance profits and ecological protection.



Overall, the dry dock policy helps reduce fishing pressure and supports long-term sustainability. But without stricter rules, like limiting catches or setting seasonal restrictions, fish stocks are still at risk. While profits go down, this policy sets the groundwork for balancing economic and environmental goals.

Analysis on Environmental tax policy

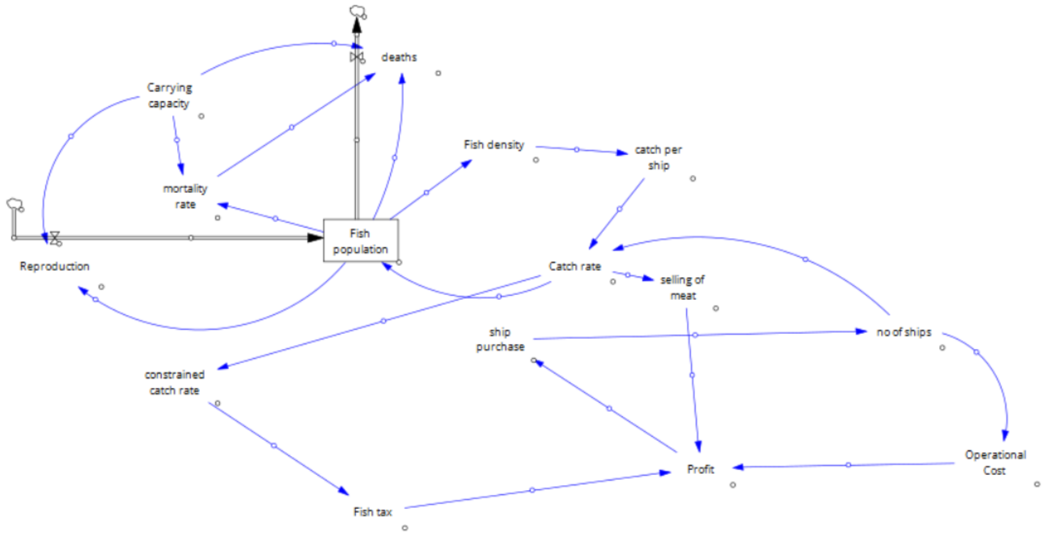
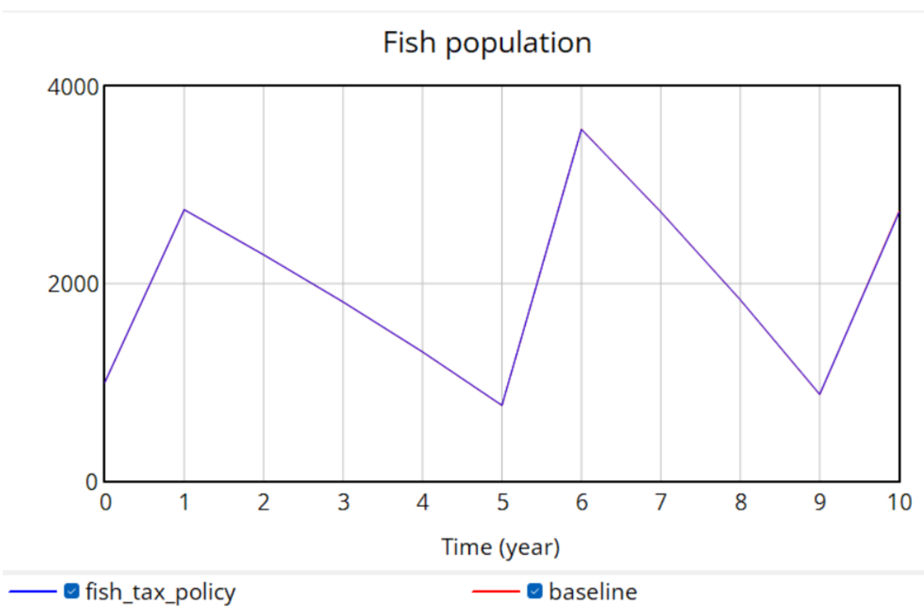
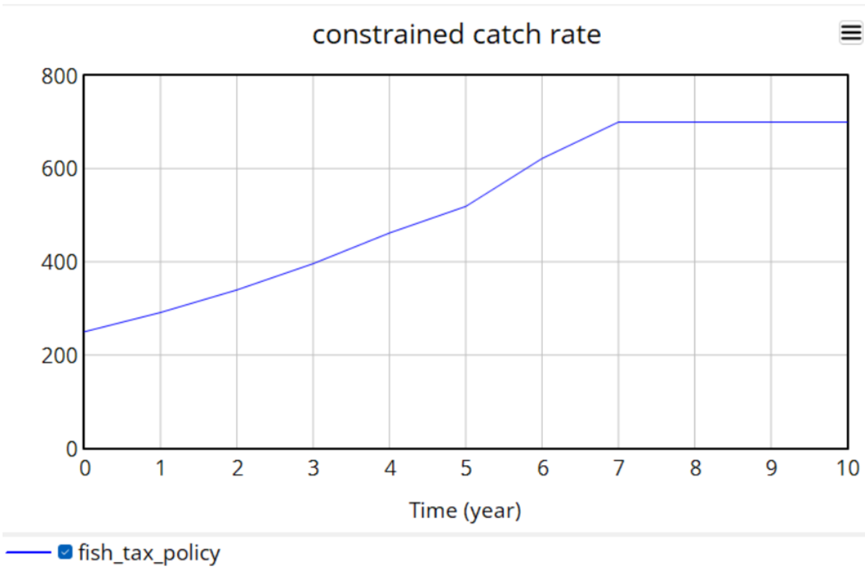


Fig 13 : Vensim model

The environmental tax policy imposes a charge per fish caught, aiming to control overfishing by increasing costs as catch rates rise.

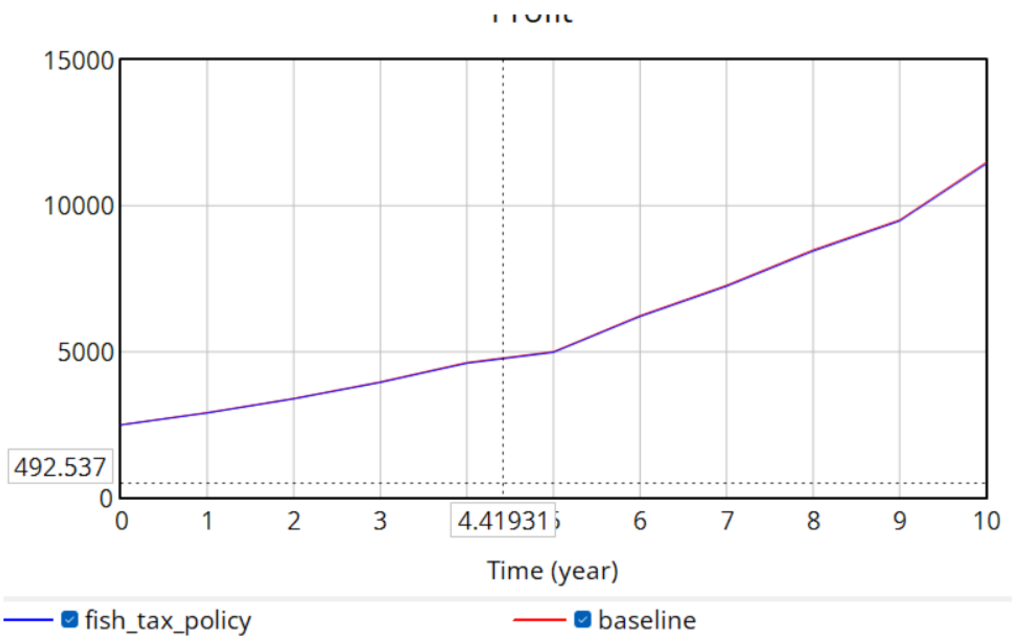


Under the environmental tax policy, the fish population stabilizes slightly better by Year 10, reaching **2,722.1**, compared to **2,735.28** in the baseline model. This small difference shows the tax doesn't directly improve the fish population much. Similarly, fish density remains nearly the same, indicating that the policy doesn't do much to reduce fishing pressure on the ecosystem. The policy slightly weakens the reinforcing loop of overfishing by increasing costs, but it doesn't provide strong ecological protection.



Catch rates stay almost unchanged, peaking at 1,144.85 in Year 10 under the tax policy compared to 1,149.05 in the baseline. This tiny difference shows the tax doesn't stop fishermen from going for the maximum catch.

The tax policy impacts costs more than fishing behavior, leaving catch rates nearly identical to the baseline.



Profits under the tax policy are slightly lower initially, starting at **$2,491.07** compared to **$2,500** in the baseline. However, by Year 10, profits are nearly identical, reaching **$11,434** under the tax policy versus **$11,490.5** in the baseline.

While the tax raises costs, fishermen adapt over time, and the financial impact fades without changing fishing behavior.Overall, the environmental tax policy doesn't do much to reduce overfishing. It creates minor financial pressure but fails to significantly affect catch rates, profits, or fish populations. For better results, this policy needs to be paired with stricter rules, like catch limits or fleet size restrictions, to truly balance economic and environmental goals.

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