Vineyard to Volume: Scaling Wine Production Using CPM Analysis

BSc Data Science: Semester 5

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CERTIFICATE

This is to certify that this project entitled "**Vineyard to Volume: Scaling Wine Production Using CPM Analysis**" is the result of research work done by **Jerin Mathew**, under my supervision. I also certify this work has not been submitted by him/her previously to this or any other University for any Degree or Diploma.

Place: Bengaluru

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CERTIFICATE

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This is to certify that this project entitled "**Vineyard to Volume: Scaling Wine Production Using CPM Analysis**" is the result of research work done by **Harsh Manchanda**, under my supervision. I also certify this work has not been submitted by him/her previously to this or any other University for any Degree or Diploma.

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Sincerely,

Jerin Mathew, Jia Bindra, Harsh Manchanda

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Abstract

This project focuses on optimizing the wine production process using the Critical Path Method (CPM) to facilitate the transition from small-scale to large-scale production. By breaking down key stages such as harvesting, fermentation, aging, and bottling, the analysis identifies critical activities that dictate the overall production timeline and bottlenecks that could hinder scaling efforts. Time estimates for each task are calculated to establish the critical path, highlighting areas for resource reallocation and process improvement. The results of the CPM analysis offer recommendations to streamline operations, reduce delays, and efficiently manage resources, enabling the production scale-up while maintaining product quality and cost-effectiveness.

Keywords

Wine production, Critical path method (CPM), Operations research, Production Scheduling, Project Management, Scaling Production, Bottleneck analysis, Resource allocation, Process optimization, Network diagram

1. Introduction

The global wine industry is witnessing a significant increase in demand, prompting wineries to scale their operations from small-scale, artisanal production to large-scale, industrial production. Efficient production processes are essential to meet this demand without compromising the quality of the final product. The complexity of wine production lies in its multi-stage, time-sensitive processes, including grape harvesting, fermentation, aging, bottling, and packaging. Any inefficiency in these stages can lead to delays, increased costs, and quality degradation.

To address these challenges, **Operations Research (OR)** techniques such as the **Critical Path Method (CPM)** can be employed to optimize production scheduling and resource allocation. This project aims to analyze a small-scale wine production process using CPM and extend the findings to scale operations efficiently. CPM will help identify critical activities, potential bottlenecks, and resource optimization strategies to ensure a smooth transition to large-scale production.

This project serves as a case study of scaling a small-scale wine production process, originally managed by our client, from producing 6 bottles per batch to an ambitious target of 600 bottles. This tenfold increase in output requires a highly structured approach, with the aim of balancing quality control and cost-effectiveness while meeting increased market demands.

1.1 Wine Production

1.1.1 The Importance of Wine Production Efficiency

Wine production is a highly complex process, divided into multiple stages, each of which has its own time and resource requirements. Efficient coordination of these activities is key to ensuring smooth operations. In the current small-scale setup, production is managed manually, but the need to scale up requires more industrial techniques, such as automation and resource reallocation, while maintaining the same high quality of handcrafted wine.

The most significant challenges we face include sourcing larger quantities of ingredients, adapting each stage of the process for higher volumes, and optimizing both time and cost through careful planning and project management.

1.1.2 The Wine Production Process

Wine production is a complex series of interdependent activities, each with varying durations and resource requirements. These activities can be grouped into several key stages:

- **Grape Harvesting**: The first and crucial stage in wine production, which involves the collection of grapes either manually or mechanically. Timing is critical since the quality of grapes directly impacts the flavor profile of the wine.
- **Crushing and Pressing**: After harvesting, the grapes are crushed to extract the juice. This step is often mechanized in large-scale operations to enhance efficiency.
- **Fermentation**: The extracted grape juice undergoes fermentation, where sugars are converted into alcohol by yeast. This stage is highly time-sensitive and must be carefully monitored to ensure the desired wine quality.
- **Clarification**: Post-fermentation, the wine is clarified to remove any solid particles or impurities.
- **Aging**: In this stage, the wine is aged to develop its flavor and character. Aging can take place in barrels or stainless-steel tanks, and its duration can vary greatly depending on the type of wine.
- **Bottling and Packaging**: The final stage involves bottling the wine, labeling, and preparing it for distribution.

Each of these activities has varying durations and resource dependencies, and the efficiency of the production process depends on how well these tasks are coordinated.

1.1.3 Scaling in Wine Production Process

Step 1: Ingredient Sourcing and Quantification

The first phase of this project involves scaling up the ingredient sourcing process. Currently, our client produces 6 bottles per batch using meticulously measured quantities of red grapes, sugar, yeast, and water, among other key ingredients. To scale up to 600 bottles, we need to accurately predict the necessary quantities of each ingredient while preserving the flavor profile and quality that define our handcrafted wine.

As we scale, local markets may no longer suffice for sourcing, particularly due to the larger quantities required. For instance, red grapes, which are locally sourced from shop vendors, might now need to be procured in bulk from nearby markets to ensure both cost-efficiency and a reliable supply. This transition from local to bulk sourcing represents a critical aspect of the scaling process and requires careful consideration of factors such as seasonal availability and cost fluctuations.

Step 2: Time and Cost Estimation for Production Processes

Following ingredient quantification, the second phase focuses on estimating both the time and cost associated with each production stage. Wine-making is inherently a multi-step process, beginning with collecting the ingredients and moving through stages such as fermentation, aging, and bottling. Our client currently manages these tasks manually, but with the scale-up, we anticipate introducing new equipment and labor resources.

Key equipment such as fermentation vats, grape crushers, and bottling machines will be integral to handling larger quantities, and accurate cost estimates will be essential for managing overheads. Additionally, labor will need to be introduced to support our client, who currently manages the 6-bottle process on her own. This will further influence both time and cost, making it vital to document and analyze each step carefully.

The precise time allocation for each activity will provide insight into potential bottlenecks and inefficiencies, guiding the optimization process as we aim to meet the production goals.

Step 3: Process Optimization Using CPM

The final phase of this project revolves around Critical Path Method (CPM) analysis, which will help identify the most time-sensitive activities in the wine production process. CPM will enable us to break down the production flow into specific tasks, determine the time required for each, and highlight the critical path—the sequence of tasks that directly affects the overall timeline.

For instance, fermentation is a critical activity in wine-making that has strict time dependencies. Any delay in this stage will cascade down to subsequent stages, such as aging and bottling. By using CPM, we can identify which activities have zero slack, meaning they cannot be delayed without affecting the entire process, and focus our efforts on optimizing those critical activities.

1.1.4 Challenges in Scaling Wine Production

Scaling wine production introduces numerous challenges that do not arise in small batches. In larger batches, even slight variations in ingredient quality, fermentation time, or temperature control can dramatically affect the outcome of the wine. Thus, scaling requires more precision in monitoring and controlling these variables.

Fermentation, for example, becomes more complicated as the volume increases. Larger vats require different temperature regulation systems, and the fermentation period may need adjustments based on the increased volume. Another major challenge is the sourcing and sterilization of bottles for a 600-bottle output. This introduces logistical considerations that our client hasn't faced with her smaller batches.

1.1.5 Leveraging CPM for Efficient Scaling

The use of CPM in scaling wine production offers several advantages. It provides clarity on which activities are critical and where there is slack, allowing for better resource management. Moreover, it enables early identification of potential bottlenecks, ensuring timely interventions to prevent delays. In addition, CPM helps guide decision-making for scaling, particularly in terms of investing in labor, machinery, and facilities.

With a clear understanding of the production process, our objective is to ensure a smooth transition from small-scale to large-scale wine production. This structured approach, backed by CPM analysis, will help us not only meet the growing demand but also preserve the quality and reputation of our handcrafted wine.

As the project progresses, each of these phases will be further analyzed to ensure the most efficient, cost-effective, and high-quality production process possible.

1.2 Operations Research in Product Scheduling

Operations Research (OR) provides a set of analytical tools that can be applied to production and scheduling challenges. **Project Scheduling** is a significant area of OR that deals with determining the optimal sequence of tasks to complete a project efficiently. Two common methods in project scheduling are **CPM (Critical Path Method)** and **PERT (Program Evaluation Review Technique)**. In this project, we use CPM, which is ideal for deterministic time estimates, to analyze and optimize wine production processes.

1.2.1 The Critical Path Method (CPM)

The **Critical Path Method (CPM)** is a project scheduling technique used to determine the longest sequence of activities (i.e., the **critical path**) that must be completed to finish the project in the shortest possible time. Activities on the critical path have zero slack (or float), meaning any delay in these activities directly affects the overall project timeline. Non-critical activities have slack, allowing for flexibility in scheduling without delaying the project.

The steps involved in applying CPM to a project are as follows:

- **List of Activities**: Break down the entire project into individual tasks or activities.
- **Time Estimates**: For each activity, estimate the duration it will take to complete. In CPM, only one deterministic time estimate is used, unlike PERT, which uses optimistic, most likely, and pessimistic estimates.
- **Precedence Relationships**: Identify dependencies between activities, i.e., which activities must be completed before others can start.
- **Network Diagram**: Construct a network diagram that represents the project's activities and their dependencies. This is often done using the Activity-on-Node (AON) or Activity-on-Arrow (AOA) method.
- **Calculate the Critical Path**: Use forward and backward passes to calculate the earliest start (ES), earliest finish (EF), latest start (LS), and latest finish (LF) times for each activity. The critical path is identified as the sequence of activities with zero slack.

1.2.2 CPM Formulas

The formulas used in CPM analysis are straightforward but crucial for calculating the project timeline.

- **Earliest Start (ES) and Earliest Finish (EF)**:
  - $ES_i = \max(EF\ of\ all\ predecessor\ activities)$
  - $EF_i = ES_i + t_i$, $where\ t_i\ is\ the\ duration\ of\ activity\ i$
- **Latest Start (LS) and Latest Finish (LF)**:
  - $LF_i = \min(LS\ of\ all\ successor\ activities)$
  - $LS_i = LF_i - t_i$
- **Slack (Float)**: The difference between the Latest Start (LS) and Earliest Start (ES) or between Latest Finish (LF) and Earliest Finish (EF).
  - $Slack\ (S) = LS - ES = LF - EF$

1.3 Transitioning from Small-Scale to Large-Scale Production

The shift from small-scale to large-scale wine production introduces several challenges in terms of resource allocation, equipment, time management, and process coordination. Large-scale production requires careful planning to ensure that each stage of the process, particularly the critical activities identified through CPM, is optimized to prevent bottlenecks.

1.3.1 Scaling Production Activities

In small-scale operations, many activities, such as grape harvesting and crushing, may be done manually or with minimal equipment. As production scales, mechanization and automation become necessary to handle larger quantities of grapes, longer fermentation times, and increased bottling needs. Scaling each stage of wine production, therefore, involves:

- **Resource Allocation**: Additional labor, machinery, and storage space must be allocated to critical activities such as crushing, fermentation, and aging.
- **Time Adjustments**: The time required for each activity may change as larger volumes of wine are processed simultaneously. For instance, the fermentation process may take longer due to larger vats, or additional aging facilities may be required to meet demand.

Using CPM, we can simulate how increasing the volume of production affects the duration of each activity and the overall project completion time.

1.3.2 Bottleneck Identification

Bottlenecks in the production process occur when resources are constrained, or certain activities take longer than anticipated. For example, if fermentation tanks are limited, the fermentation process may delay subsequent stages such as aging and bottling. Identifying these bottlenecks using CPM allows for proactive resource management, such as purchasing additional fermentation tanks or hiring more staff to speed up harvesting.

1.4 Importance of CPM in Large-Scale Wine Production

The application of CPM in scaling wine production offers several advantages:

- **Improved Scheduling**: CPM helps identify the critical path, ensuring that delays in critical activities are minimized. It also highlights slack in non-critical activities, providing flexibility in resource management.
- **Bottleneck Prevention**: CPM enables the early identification of bottlenecks, allowing management to address potential delays before they impact the entire production process.
- **Resource Optimization**: By analyzing the time requirements and slack of each activity, resources such as labor, machinery, and storage space can be allocated more efficiently, reducing costs and improving overall production efficiency.
- **Decision Making for Scaling**: With the critical path identified, management can make informed decisions about where to invest in additional resources or automation to handle the increased volume of production.

The introduction of CPM into wine production allows for a structured approach to managing the complexity of scaling operations. By breaking down the wine production process into individual activities, estimating their time requirements, and identifying critical dependencies, CPM provides a clear roadmap for efficient scheduling. As the project moves forward, this analysis will be key in ensuring a smooth transition from small-scale to large-scale production, minimizing delays, and optimizing resource usage to meet increasing market demands. The subsequent sections will dive deeper into the detailed analysis, calculations, and recommendations for scaling wine production using the Critical Path Method.

2. Literature Review

The application of operations research (OR) and network analysis has seen growing relevance across industries, particularly in wine production and the progression from small-scale to large-scale industries. The literature demonstrates a rich interplay between the optimization of supply chain networks and the scaling challenges faced by businesses, offering insights into how firms can evolve and innovate for greater efficiency.

Operations Research and Network Analysis in Wine Production

Wine production has emerged as a unique case study in operations research, with several key scholars addressing the optimization of supply chains and network structures within the industry. **Saglietto et al. (2011)** explored the wine supply chain in Argentina and France, comparing the dynamics of logistics service providers within the context of social network analysis. Their study examined how the structure of networks influences strategic orientations within wine production, highlighting the importance of interconnectivity among stakeholders. This work laid the foundation for understanding how network design can directly impact efficiency and production strategies in the wine industry (Saglietto et al., 2011).

Similarly, **Montaigne and Coelho (2012)** delved into the structure of wine-producing firms, focusing on typologies and clusters within the industry. They identified key factors such as grape growers and co-operatives, who form complex networks of relationships. This research emphasized the role of intermediaries, which are essential for creating a robust supply chain but often overlooked in traditional analyses (Montaigne & Coelho, 2012).

Building on this foundation, **Varsei and Polyakovskiy (2017)** presented a more detailed examination of sustainable supply chain design, particularly within Australia's wine sector. Their research applied OR principles to develop more innovative and sustainable business models, optimizing the supply chain for greater environmental and economic efficiency. This focus on sustainability is critical in modern wine production, where resource constraints such as water usage have come under increased scrutiny (Varsei & Polyakovskiy, 2017).

Moreover, **Maesano et al. (2022)** conducted a comprehensive environmental assessment of the wine supply chain through network analysis, emphasizing the clustering of research around sustainability trends. Their work offers insights into the environmental impact of wine production and the role that technological innovation and network optimization can play in reducing the industry's footprint (Maesano et al., 2022).

Transitioning from Small-Scale to Large-Scale Industries

While the wine industry offers a focused look at network optimization, the broader economic literature addresses the transformation of small-scale industries into large-scale enterprises. **Liedholm and Mead (1987)** investigated the evolution of small industries in developing countries, providing empirical evidence of how small-scale firms contribute to national economies. Their findings underscore the importance of fostering small industries to achieve long-term economic growth, yet also highlight the challenges these businesses face in scaling up to compete on a global stage (Liedholm & Mead, 1987).

Ogechukwu (2011) further explored the role of small-scale industries in national development, particularly in Nigeria. His research detailed the barriers these industries encounter, such as access to capital, regulatory constraints, and infrastructure limitations. Ogechukwu argued that for small-scale businesses to evolve into larger enterprises, there must be a concerted effort to address these systemic challenges (Ogechukwu, 2011).

Rasmussen and Schmitz (1992) introduced the concept of flexible specialization, where small-scale industries could maintain their agility while adapting to larger-scale operations. This approach advocates for specialization to achieve competitiveness without the burdens of large-scale operations. By focusing on niche markets and leveraging specialized skills, small firms can thrive even as they expand (Rasmussen & Schmitz, 1992).

Finally, **Romijn (2001)** provided a crucial perspective on technological support for small industries, particularly in developing countries. He examined how access to technology enables small businesses to transition to larger-scale operations by improving efficiency, output quality, and market reach. However, Romijn stressed the need for robust policy frameworks to support this technological transition (Romijn, 2001)

While there is extensive research on optimizing various production processes, we identified a notable gap in the application of Critical Path Method (CPM) in the wine industry. Specifically, there is a lack of studies that focus on upscaling the wine production process using CPM techniques. This gap presents an opportunity to explore how CPM can enhance efficiency and scalability in wine production.

In summary, the convergence of operations research, network analysis, and the scaling of small-scale industries illustrates a dynamic and interconnected narrative of economic development. From the highly specialized wine industry to the broader context of industrial scaling, the literature demonstrates how optimization strategies and technological advancements can empower businesses to grow sustainably. As these industries continue to evolve, the application of OR models and network analysis will remain central to addressing both environmental concerns and economic growth. By understanding these connections, businesses can better position themselves to navigate the complexities of scaling while maintaining operational efficiency and sustainability.

3. Methodology

This project employs the Critical Path Method (CPM) to analyze and optimize the wine production process, facilitating a transition from small-scale to large-scale operations. The methodology is designed to systematically break down the production process into key stages—harvesting, fermentation, aging, and bottling—and identify critical activities that determine the overall production timeline. By calculating time estimates and identifying bottlenecks, this analysis will help ensure a streamlined production process that maintains both quality and cost-effectiveness during the scale-up from 6 bottles per batch to 600 bottles.

3.1 Objectives

1. **Predict ingredient quantities for large-scale production:** Estimate the quantities of raw materials, such as grapes, yeast, and water, required to produce 600 bottles of wine while maintaining the same flavor profile and quality as small-batch production.

2. **Calculate the minimum time to complete the wine-making process**: Using CPM, calculate the shortest possible duration for the entire wine production process, from harvesting to bottling, by determining the critical path.

3. To find critical activities of wine making process

4. Identify bottlenecks and critical activities: Pinpoint the stages of the wine-making process that are most time-sensitive and could hinder production efficiency, such as fermentation, which directly impacts subsequent stages.

5. Optimize resource allocation: Propose adjustments to labor, equipment, and scheduling to maximize efficiency and ensure smooth transitions between production stages.

6. Estimate production costs: Calculate the total cost of scaling up the production process, including expenses related to equipment, labor, and ingredient sourcing.

By applying CPM, this methodology provides a structured framework for optimizing time, resources, and cost in the transition to large-scale wine production.

3.2 Data Collection

3.2.1 Data Provided by Client

For our analysis, the client provided detailed information on the process of them (1 person) making wine for six bottles. This includes the step-by-step procedure, along with the time taken and the cost associated with each step. The breakdown covers everything from ingredient collection to the final bottling and corking process. This data serves as the foundation for scaling up the production to 600 bottles using the Critical Path Method (CPM). Below is a detailed table outlining the various stages, the time required, and the cost incurred for each process:

Table 1: **Detailed Breakdown of Wine Production Process for Six Bottles**

Process	Count	Time (hours)	Cost (₹)
Collecting clove (10 pieces)	10	0.25	5.5
Collecting cardamom (10 pieces)	10	0.25	20
Collecting star anise (10.5 pieces)	10.5	0.25	7.5
Collecting cinnamon (1 inch)	1	0.01667	2.1
Collecting ginger (1 inch)	1	0.01667	2.5
Drying the ingredients (including sterilizing)		2	0
Collecting red grapes (kg)	2	0.5	180

Cleaning the grapes (salt water + 3 times water)		0.5	0
Dry the grapes		1	0
Collect water (litre)	3.5	0.16667	0
Boil and cool to normal temperature		0.5	10
Collect sugar (kg)	0.75	0.25	32
Yeast (teaspoon)	1	0.25	3
Whole wheat (teaspoon)	12	0.5	33
Get 10L barrel (clay)	10	1.66667	1000
Get lid		0.01667	300
Get wooden spoon		0.01667	200
Get cotton cloth (metre)	0.5	0.00833	100
Crush grapes with a wooden spoon in barrel		0.08333	0
Add sterilized spices		0.25	0
Dissolve sugar into 3.5 litre water		0.25	0
Add sugar water into the barrel		0.25	0
Add wheat extract		0.25	0
Add yeast		0.25	0
Stir using wooden spoon - stir only one direction for 3 mins slowly		0.05	0
Close using lid tightly using cotton cloth		0.08333	0
Keep barrel in a dark room (3 days)		72	0
After 3 days, open and stir in one direction for 3-4 mins		0.06667	0
Again close the lid tightly		0.08333	0
Repeat the process for 15 days		360	0
Rest for 3 days		72	0
21st day, take it and filter the wine		0.5	0
Sterilize the bottles for at least one day		24	100
Pour the wine into bottles (6 bottles)		0.33333	300
Close bottles using a cork		0.08333	100

The client estimates that the current wine production process can efficiently produce up to 50 bottles with a single individual managing all tasks. However, scaling beyond this quantity would require additional labor and the introduction of industrial-level equipment to handle the increased workload. This shift is necessary to maintain efficiency and ensure timely completion of the process. The need for advanced resources arises as the complexity and volume of tasks grow with larger production goals.

3.2.2 Data Collection and Breakdown for Wine Production (600 Bottles)

To calculate the production data for 600 bottles of wine, the data collection process is divided into two parts:

Calculating the Quantity of Ingredients (Count)

We first need to determine the precise quantity of ingredients required to scale up the production. The quantity of ingredients like clove, cardamom, red grapes, and yeast increases proportionally based on the number of bottles being produced. We have gathered the quantity of ingredients (count) for 1, 6 and 50 bottles from the client to calculate for 600 bottles:

Table 2: **Ingredients and Materials Required for 1 Bottle of Wine Production**

FOR 1 BOTTLE	
collecting clove	4
collecting cardamom	4
collecting staranise	4
collecting cinnamon(inch)	1
collecting wheat(teaspoon)	2
collecting ginger(inch)	0.5
collecting red grapes(kg)	0.5
collect water(litre)	0.75
collect sugar(kg)	0.35
yeast(teaspoon)	0.5
get L Barrel(clay)	3
get cotton cloth(metre)	1

Table 3: **Ingredients and Materials Required for 6 Bottles of Wine Production**

FOR 6 BOTTLES	
collecting clove (10)	10
collecting cardamom (10)	10
collecting staranise (10.5)	10.5
collecting cinnamon (1 inch)	1
collecting wheat	8
collecting ginger (1 inch)	1
collecting red grapes (kg)	2
collect water (litre)	3.5
collect sugar (kg)	0.75
Yeast (teaspoon)	1
get 10L Barrel (clay)	10
get cotton cloth (metre)	1

Table 4: **Ingredients and Materials Required for 50 Bottles of Wine Production**

FOR 50 BOTTLES	
collecting clove	142
collecting cardamom	142
collecting staranise	142
collecting cinnamon(inch)	29
collecting wheat(teaspoon)	83
collecting ginger(inch)	17
collecting red grapes(kg)	21
collect water(litre)	33
collect sugar(kg)	12
yeast(teaspoon)	17
get L Barrel(clay)	117
get cotton cloth(metre)	50

Data Generation Through Interpolation

To effectively utilize a feedforward neural network for predicting ingredient quantities, it is crucial to have a sufficient amount of training data. In our case, we initially had data points for only 1, 6, and 50 bottles. To bridge this gap and create a more comprehensive dataset, we employed linear interpolation. This method was selected due to the observed trend that the rate of ingredient count increases as the number of bottles increases. By applying linear interpolation, we generated additional data points between our existing values, allowing us to create a more robust dataset for training our neural network. This approach enhances the model's ability to learn patterns and make accurate predictions across a wider range of inputs.

x	clove(number)	Cardomom(number)	staranise(number)	cinnamon	wheat extract(teaspoon)	ginger(inch)	red grapes(kg)	water(litre)	sugar(kg)	east(teaspoon)
1	4	4	4	1	2	0.5	0.5	0.75	0.35	0.5
2	5.2	5.2	5.2	1	3.2	0.6	0.8	1.3	0.43	0.6
3	6.4	6.4	6.4	1	4.4	0.7	1.1	1.85	0.51	0.7
4	7.6	7.6	7.6	1	5.6	0.8	1.4	2.4	0.59	0.8
5	8.8	8.8	8.8	1	6.8	0.9	1.7	2.95	0.67	0.9
6	10	10	10	1	8	1	2	3.5	0.75	1
7	13	13	13	1.636363636	9.704545455	1.3636	2.4318	4.1705	1.0057	1.3636
8	16	16	16	2.272727273	11.40909091	1.7273	2.8636	4.8409	1.2614	1.7273
9	19	19	19	2.909090909	13.11363636	2.0909	3.2955	5.5114	1.517	2.0909
10	22	22	22	3.545454545	14.81818182	2.4545	3.7273	6.1818	1.7727	2.4545
11	25	25	25	4.181818182	16.52272727	2.8182	4.1591	6.8523	2.0284	2.8182
12	28	28	28	4.818181818	18.22727273	3.1818	4.5909	7.5227	2.2841	3.1818
13	31	31	31	5.454545455	19.93181818	3.5455	5.0227	8.1932	2.5398	3.5455
14	34	34	34	6.090909091	21.63636364	3.9091	5.4545	8.8636	2.7955	3.9091
15	37	37	37	6.727272727	23.34090909	4.2727	5.8864	9.5341	3.0511	4.2727
16	40	40	40	7.363636364	25.04545455	4.6364	6.3182	10.2045	3.3068	4.6364
17	43	43	43	8	26.75	5	6.75	10.875	3.5625	5
18	46	46	46	8.636363636	28.45454545	5.3636	7.1818	11.5455	3.8182	5.3636
19	49	49	49	9.272727273	30.15909091	5.7273	7.6136	12.2159	4.0739	5.7273
20	52	52	52	9.909090909	31.86363636	6.0909	8.0455	12.8864	4.3295	6.0909
21	55	55	55	10.54545455	33.56818182	6.4545	8.4773	13.5568	4.5852	6.4545
22	58	58	58	11.18181818	35.27272727	6.8182	8.9091	14.2273	4.8409	6.8182
23	61	61	61	11.81818182	36.97727273	7.1818	9.3409	14.8977	5.0966	7.1818
24	64	64	64	12.45454545	38.68181818	7.5455	9.7727	15.5682	5.3523	7.5455
25	67	67	67	13.09090909	40.38636364	7.9091	10.2045	16.2386	5.608	7.9091
26	70	70	70	13.72727273	42.09090909	8.2727	10.6364	16.9091	5.8636	8.2727
27	73	73	73	14.36363636	43.79545455	8.6364	11.0682	17.5795	6.1193	8.6364
28	76	76	76	15	45.5	9	11.5	18.25	6.375	9
29	79	79	79	15.63636364	47.20454545	9.3636	11.9318	18.9205	6.6307	9.3636
30	82	82	82	16.27272727	48.90909091	9.7273	12.3636	19.5909	6.8864	9.7273
31	85	85	85	16.90909091	50.61363636	10.0909	12.7955	20.2614	7.142	10.0909
32	88	88	88	17.54545455	52.31818182	10.4545	13.2273	20.9318	7.3977	10.4545
33	91	91	91	18.18181818	54.02272727	10.8182	13.6591	21.6023	7.6534	10.8182
34	94	94	94	18.81818182	55.72727273	11.1818	14.0909	22.2727	7.9091	11.1818
35	97	97	97	19.45454545	57.43181818	11.5455	14.5227	22.9432	8.1648	11.5455
36	100	100	100	20.09090909	59.13636364	11.9091	14.9545	23.6136	8.4205	11.9091
37	103	103	103	20.72727273	60.84090909	12.2727	15.3864	24.2841	8.6761	12.2727
38	106	106	106	21.36363636	62.54545455	12.6364	15.8182	24.9545	8.9318	12.6364
39	109	109	109	22	64.25	13	16.25	25.625	9.1875	13
40	112	112	112	22.63636364	65.95454545	13.3636	16.6818	26.2955	9.4432	13.3636
41	115	115	115	23.27272727	67.65909091	13.7273	17.1136	26.9659	9.6989	13.7273
42	118	118	118	23.90909091	69.36363636	14.0909	17.5455	27.6364	9.9545	14.0909
43	121	121	121	24.54545455	71.06818182	14.4545	17.9773	28.3068	10.2102	14.4545
44	124	124	124	25.18181818	72.77272727	14.8182	18.4091	28.9773	10.4659	14.8182
45	127	127	127	25.81818182	74.47727273	15.1818	18.8409	29.6477	10.7216	15.1818
46	130	130	130	26.45454545	76.18181818	15.5455	19.2727	30.3182	10.9773	15.5455
47	133	133	133	27.09090909	77.88636364	15.9091	19.7045	30.9886	11.2329	15.9091
48	136	136	136	27.72727273	79.59090909	16.2727	20.1364	31.6591	11.4886	16.2727
49	139	139	139	28.36363636	81.29545455	16.6364	20.5682	32.3295	11.7443	16.6364
50	142	142	142	29	83	17	21	33	12	17

Implementing Neural Network

The interpolated data consisted of 50 data points representing the number of bottles and their corresponding ingredient quantities. We constructed a neural network using Keras, defining a sequential model with:

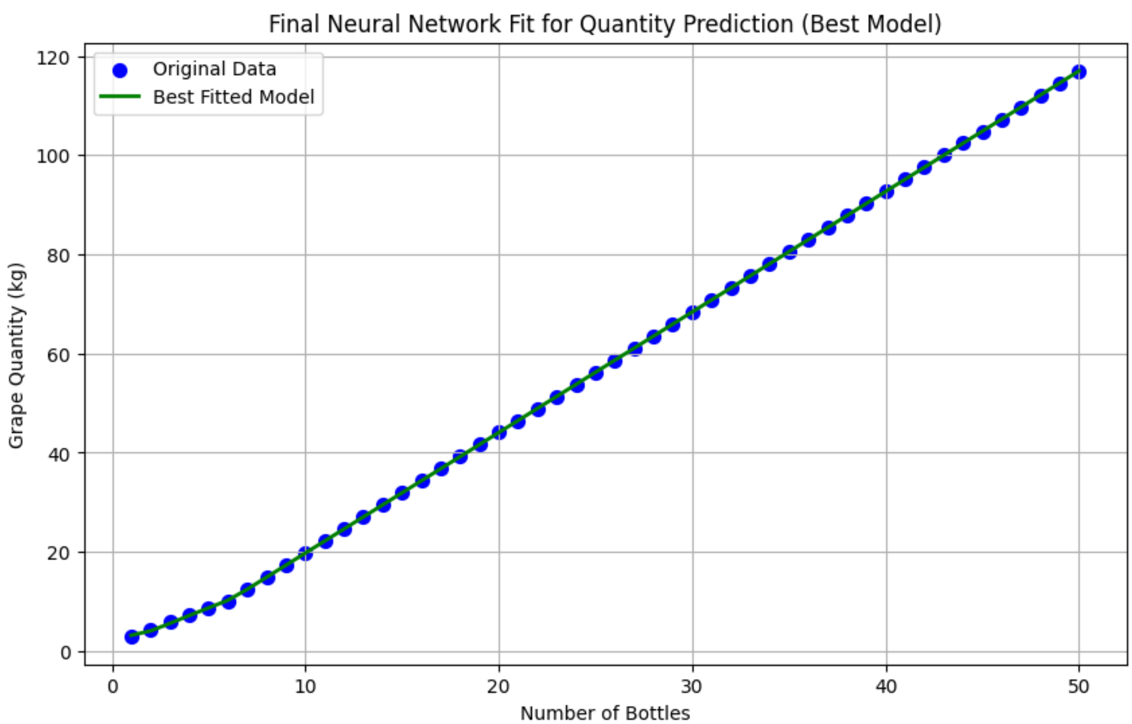
- An input layer connected to a hidden layer with 10 neurons, utilizing the ReLU activation function to introduce non-linearity.
- A second hidden layer with 5 neurons.
- An output layer that predicts the quantity of ingredients.

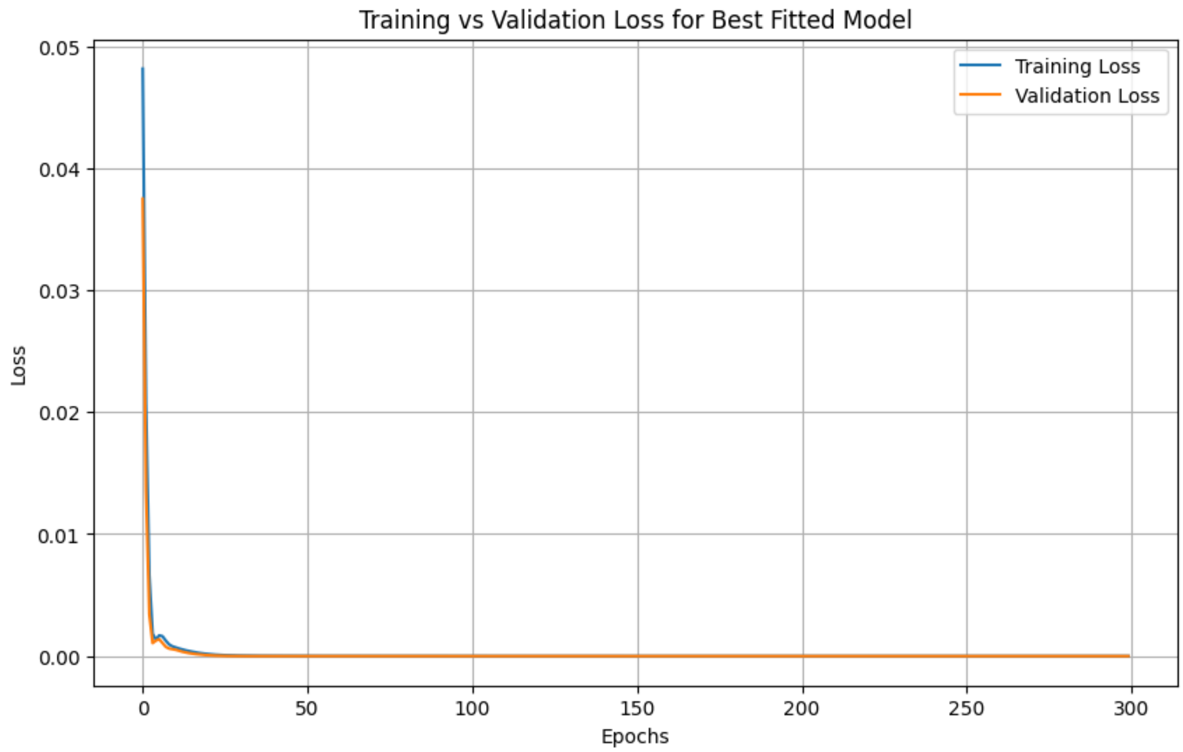
The model was compiled with the Adam optimizer and mean squared error (MSE) as the loss function, which is appropriate for regression tasks.

We divided the dataset into training and testing sets using an 80-20 split. To enhance robustness, we trained multiple models (5 in this case) and evaluated each based on their MSE on the test set. During training, we utilized a validation split to monitor performance and avoid overfitting.

After training, we selected the best-performing model based on the lowest MSE. Using this model, we made predictions for a specific input—600 bottles. The final prediction was derived from scaling back the normalized output to its original range.

Throughout the process, we generated plots to visualize the model's fit against the original data points, helping to illustrate the relationship learned by the neural network. Additionally, we plotted training and validation loss to assess the model's learning progression over epochs.





In summary, this methodology harnessed the power of neural networks to effectively interpolate and predict ingredient quantities, demonstrating a structured approach to data preparation, model training, and evaluation. The neural network code is mentioned in the Appendix.

Table 5: **Predicted Values Using Neural Network**

FOR 600 BOTTLES	
collecting clove	1794.75
collecting cardamom	1794.75
collecting staranise	1794.75
collecting cinnamon(inch)	217
collecting wheat(teaspoon)	1021.86
collecting ginger(inch)	217.36
collecting red grapes(kg)	258.85
collect water(litre)	397.09
collect sugar(kg)	152.86
yeast(teaspoon)	217.36
get L Barrel(clay)	1456.73
get cotton cloth(metre)	22

Calculating the time and cost for 600 bottles

To accurately predict the time and cost associated with producing 600 bottles of wine, we considered various operational factors, including labor, equipment, and facility rental. Specifically, we introduced one laborer at a daily wage of ₹700 to assist with the production process. Additionally, we accounted for the rental cost of a facility to store barrels for fermentation, which is set at ₹10,000 per month.

For equipment, we included several key items essential for the production process: a fruit washing machine for cleaning grapes, a dehydrator for drying spices, a wine crusher for crushing grapes, and clay barrels with a capacity of 50 liters each for fermentation. The costs for these items were determined based on current market rates.

By analyzing each of these factors and estimating the time required for each process—such as preparation, fermentation, and bottling—we developed a comprehensive model to calculate the total production time and costs involved in producing 600 bottles. This approach allows us to create a realistic financial projection and operational timeline, ensuring that all necessary resources are accounted for in the production plan.

Table 6: **Count, Time and Cost of Production Process for 600 Bottles**

process	count	time(hours)	cost
collecting clove	1795	1	200
collecting cardamom	1795	1	550
collecting staranise	1795	1	1400
collecting cinnamon(INCH)	217	1	200
collecting ginger(INCH)	217	1	521.66
drying the ingredients		8	5000(one time)
collecting red grapes(kg)	259	24	12950
cleaning the grapes by putting it in salt water		1	350
cleaning the grapes 3 times in water		1	100000
dry the grapes		1	0
collect water(litre)	397	0.5	10
boil and cool to normal temperature		3	150
collect sugar(kg)	153	0.5	6,120
yeast(teaspoon)	217	0.25	184.2
wholewheat(teaspoon)	1022	0.25	858.6
get Barrel(clay) (litre) + get lid	1457	2	32000(one time) + 4500(onetime
get wine crusher		1	175000(one time)
get cotton cloth(metre)	22	0.5	2500
crush grapes with wine crusher in barrel		3	0
add sterlized spices		0.5	0
dissolve sugar into water		0.25	0
add sugar water into the barrel		1	0
add wheat extract		1	0
add yeast		1	0
stir using long wooden spoon - stir only one direction for 3 mins slowly		45	300
close using lid tightly using cotton cloth		1.25	0
keep barrel in a dark room(3 days)		72	0
after 3 days open and stir on 1 direction for 3 - 4 mins		1	0
again close the lid tightly		1.25	0
repeat the process for 15 days		371.25	0
rest for 3 days		72	0
21st day, take it and filter the wine		0.5	75000(one time)
Sterilize the bottles for at least one day		24	600
Pour the wine into bottles (6 bottles)		5	18000
close bottles using a cork		1	3000

3.3 Implementing CPM

We employed a structured methodology to optimize the production process of 600 bottles by analyzing the critical path using the Critical Path Method (CPM). Initially, a detailed descriptive table was constructed, outlining the steps involved in the production process, along with their predecessors, time estimates, and associated costs.

Table 7: **Description Table for CPM**

STEPS	Process	Predecessor	Count	Time(hours)	Cost
A1	collecting clove		1795	1	200
A2	collecting cardamom		1795	1	550
A3	collecting staranise		1795	1	1400
A4	collecting cinnamon(INCH)	A1,A2,A3	217	1	200
A5	collecting ginger(INCH)	A1,A2,A3	217	1	521.66
A6	collecting red grapes(kg)	A4,A5	259	24	12950
A7	collect water(litre)	A6	397	0.5	10
A8	collect sugar(kg)	A4,A5	153	0.5	6,120
A9	yeast(teaspoon)	A8	217	0.25	184.2
A10	wholewheat(teaspoon)	A8	1022	0.25	858.6
A11	get Barrel(clay) (litre) + get lid	A9,A10	1457	2	32000(one time) + 4500(onetime
A12	get wine crusher	A11		1	175000(one time)
A13	get cotton cloth(metre)	A12	22	0.5	2500
A14	collect bottles	A13	600	24	
B1	drying the ingredients			8	5000(one time)
B2	cleaning the grapes by putting it in salt water			1	350
B3	soaking the grapes 3 times in water	B2		1	100000
B4	dry the grapes	B3		1	0
B5	boil and cool to normal temperature	B1		3	150
B6	crush grapes with wine crusher in barrel	B4		3	0
B7	add sterlized spices	B1,B6		0.5	0
B8	dissolve sugar into water	B5,B7		0.25	0
B9	add sugar water into the barrel	B8		1	0
B10	add wheat extract	B9		1	0
B11	add yeast	B10		1	0
B12	stir using long wooden spoon - stir only one direction for 3 mins slowly	B11		45	300
B13	close using lid tightly using cotton cloth	B12		1.25	0
C1	keep barrel in a dark room(3 days)			72	0
C2	after 3 days open and stir on 1 direction for 3 - 4 mins	C1		1	0
C3	again close the lid tightly	C2		1.25	0
C4	repeat the process for 15 days	C3		371.25	0
C5	rest for 3 days	C4		72	0
C6	21st day, take it and filter the wine	C5		0.5	75000(one time)
C7	Sterilize the bottles for at least one day	C5		24	600
C8	Pour the wine into bottles (6 bottles)	C6,C7		5	18000
C9	close bottles using a cork	C8		1	3000

This table was then segmented into three distinct phases: **Phase 1** focused on the collection of ingredients, **Phase 2** involved the assembly of these ingredients, and **Phase 3** encompassed the fermentation process. By applying CPM, we aimed to identify the critical path, which highlights the sequence of essential tasks that directly influence the overall project duration. This analysis will enable us to derive minimum time and cost estimations for the entire production process. To facilitate this, we utilized ProjectLibre software, allowing for efficient visualization and management of the project timeline and resource allocation.

Table 8: **Phase 1 Collecting Ingredients**

Collecting the ingredients					
Step	Process	Predecessor	Count	Time(hours)	Cost
A1	collecting clove		1795	1	200
A2	collecting cardamom		1795	1	550
A3	collecting staranise		1795	1	1400
A4	collecting cinnamon(INCH)	A1,A2,A3	217	1	200
A5	collecting ginger(INCH)	A1,A2,A3	217	1	521.66
A6	collecting red grapes(kg)	A4,A5	259	24	12950
A7	collect water(litre)	A6	397	0.5	10
A8	collect sugar(kg)	A4,A5	153	0.5	6,120
A9	yeast(teaspoon)	A8	217	0.25	184.2
A10	wholewheat(teaspoon)	A8	1022	0.25	858.6
A11	get Barrel(clay) (litre) + get lid	A9,A10	1457	2	32000(one time) + 4500(onetime
A12	get wine crusher	A11		1	175000(one time)
A13	get cotton cloth(metre)	A12	22	0.5	2500
A14	collect bottles	A13		24	

Table 9: **Phase 2 Assembling of Ingredients**

Assembling the ingredients				
STEP	process	predecessor	time(hours)	cost
B1	drying the ingredients		8	5000(one time)
B2	cleaning the grapes by putting it in salt water		1	350
B3	soaking the grapes 3 times in water	B2	1	100000
B4	dry the grapes	B3	1	0
B5	boil and cool to normal temperature	B1	3	150
B6	crush grapes with wine crusher in barrel	B4	3	0
B7	add sterlized spices	B1,B6	0.5	0
B8	dissolve sugar into water	B5,B7	0.25	0
B9	add sugar water into the barrel	B8	1	0
B10	add wheat extract	B9	1	0
B11	add yeast	B10	1	0
B12	stir using long wooden spoon - stir only one direction for 3 mins slowly	B11	45	300
B13	close using lid tightly using cotton cloth	B12	1.25	0

Table 10: **Phase 3 Fermentation**

Fermentation				
STEP	process	predecessor	time(hours)	cost
C1	keep barrel in a dark room(3 days)		72	0
C2	after 3 days open and stir on 1 direction for 3 - 4 mins	C1	1	0
C3	again close the lid tightly	C2	1.25	0
C4	repeat the process for 15 days	C3	371.25	0
C5	rest for 3 days	C4	72	0
C6	21st day, take it and filter the wine	C5	0.5	75000(one time)
C7	Sterilize the bottles for at least one day	C5	24	600
C8	Pour the wine into bottles (6 bottles)	C6,C7	5	18000
C9	close bottles using a cork	C8	1	3000

By applying the Critical Path Method (CPM) to each of the three phases of the production process: collecting ingredients, assembling ingredients, and fermentation; For each phase, we will identify the critical path, which represents the longest sequence of dependent tasks and helps determine the minimum time required to complete that phase. After establishing the critical paths for each phase, we will sum the minimum durations to calculate the total project duration. Similarly, we will analyze the costs associated with each phase, identifying the minimum expenditures necessary to complete the project. This comprehensive approach will ensure that we have a clear understanding of both time and cost implications, facilitating effective project management and resource allocation.

4. Results & Discussions

Phase 1: Collecting Ingredients

		Name	Duration	Predecessors
1		collecting clove	0.042 days	
2		collecting cardamom	0.042 days	
3		collecting staranise	0.042 days	
4		collecting cinnamon(INCH)	0.042 days	3;2;1
5		collecting ginger(INCH)	0.042 days	3;2;1
6		collecting red grapes(kg)	1 day	5;4
7		collect water(litre)	0.021 days	10
8		collect sugar(kg)	0.021 days	5;4
9		yeast(teaspoon)	0.01 days	8
10		wholewheat(teaspoon)	0.01 days	8
11		get Barrel(clay) (litre) + get l	0.083 days	10;9
12		get wine crusher	0.042 days	11
13		get cotton cloth(metre)	0.021 days	12
14		collect bottles	1 day?	13

We have inserted Phase 1 description table into ProjectLibre to get the graph for the critical path. Here we have converted the duration from hours to days.

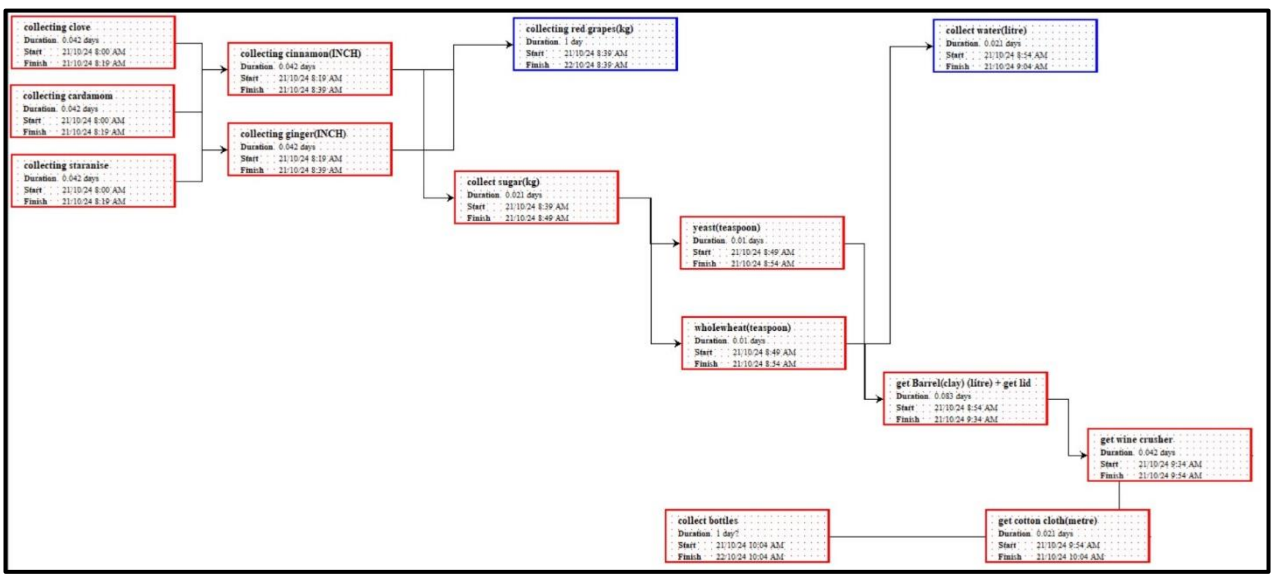


Figure 1

Here we dealt with parallel critical activities as shown in Figure 1. The client has mentioned that the ingredients which are shown as parallel critical activities are sourced from the same place and hence when calculating the time, taking the duration of one critical activity is enough instead of summing up the durations of the critical parallel activities. For instance:

Since the client mentioned that these ingredients are collected from the same location, the total time is not the sum of all activities. The duration (0.042 days) applies for all three activities simultaneously, because they occur in parallel. Therefore, for scheduling purposes, only the longest time (0.042 days) is considered, not their combined duration. Similarly the same method is used for other parallel critical activities.

Here the Critical path is: [collecting clove, cardamom, staranise] → [collecting cinnamon, ginger] →[collecting sugar] → [Collecting yeast, wholewheat] → [get clay Barrel + lid] → [Get wine crusher] → [Get cotton cloth] → [collect Bottles]

Process	Time(days)	Cost
collecting clove	0.0416	200
collecting cardamom	0.0416	550
collecting staranise	0.0416	1400
collecting cinnamon(INCH)	0.0416	200
collecting ginger(INCH)	0.0416	522
collect sugar(kg)	0.0208	6120
yeast(teaspoon)	0.0104	184
wholewheat(teaspoon)	0.0104	859
get Barrel(clay) (litre) + get lid	0.0833	
get wine crusher	0.0416	
get cotton cloth(metre)	0.0208	2500
collect bottles	1	21000

Critical Time = 0.0416+0.0416+0.0208+0.0104+0.0833+0.0416+0.0208+1

= 1.26 days = 30.24 hrs

Estimated Cost = Rs 33535

Phase 2: Assembling the Ingredients

		Name	Duration	Predecessors
1		drying the ingredients	0.333 days	
2		cleaning the grapes by putting it in salt water	0.042 days	
3		soaking the grapes 3 times in water	0.042 days	2
4		dry the grapes	0.042 days	3
5		boil and cool to normal temperature	0.125 days	1
6		crush grapes with wine crusher in barrel	0.125 days	4
7		add sterlized spices	0.021 days	1;6
8		dissolve sugar into water	0.01 days	5;7
9		add sugar water into the barrel	0.042 days	8
10		add wheat extract	0.042 days	9
11		add yeast	0.042 days	10
12		stir using long wooden spoon - stir only one direction for 3 mins slowly	0.08 days	11
13		close using lid tightly using cotton cloth	0.052 days	12

We have inserted Phase 2 description table into ProjectLibre to get the graph for the critical path. Here we have converted the duration from hours to days.

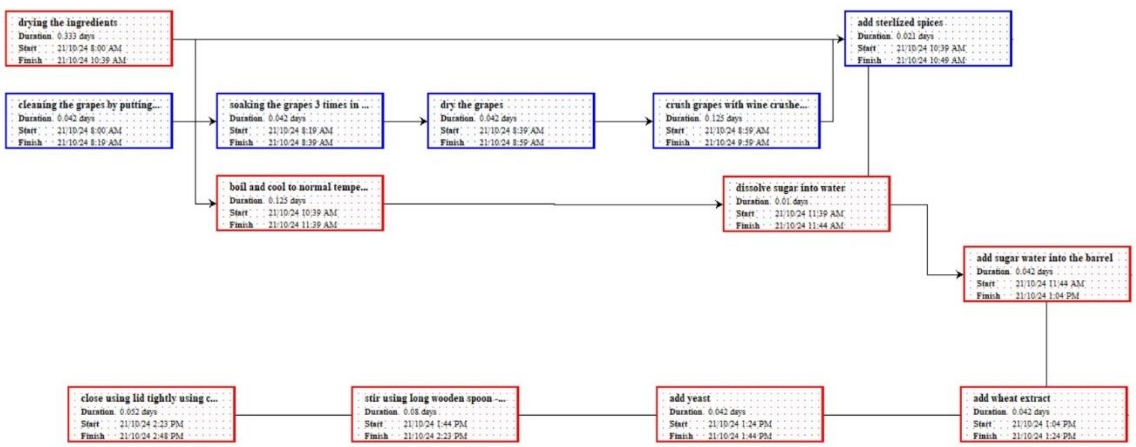


Figure 2

Here the Critical path is: [Drying Ingredients] → [Boil and Cool at Normal Temperature] → [Dissolve Sugar into Water] → [Add sugar water into the barrel] → [add wheat extract] → [add yeast] → [Stir using long wooden spoon] → [close lid tightly]

Process	Time(days)	Cost
drying the ingredients	0.3333	
boil and cool to normal temperature	0.125	150
dissolve sugar into water	0.0104	0
add sugar water into the barrel	0.0416	0
add wheat extract	0.0416	0
add yeast	0.0416	0

stir using long wooden spoon - stir only one direction for 3 mins slowly	0.0803	300
close using lid tightly using cotton cloth	0.052	

Critical Time = 0.3333+0.125+0.0104+0.0416+0.0416+0.0416+0.0803+0.052

= 0.7258 days = 17.41 hrs

Estimated Cost = Rs 450

Phase 3: Fermentation

	ⓘ	Name	Duration	Predecessors
1		keep barrel in a dark room(3 days)	3 days	
2		after 3 days open and stir on 1 direction for 3 - 4 mins	0.042 days	1
3		again close the lid tightly	0.052 days	2
4		repeat the process for 15 days	15 days	3
5		rest for 3 days	3 days	4
6		21st day, take it and filter the wine	0.021 days	5
7		Sterilize the bottles for at least one day	1 day	5
8		Pour the wine into bottles (6 bottles)	0.208 days	6;7
9		close bottles using a cork	0.042 days	8

We have inserted Phase 3 description table into ProjectLibre to get the graph for the critical path. Here we have converted the duration from hours to days.

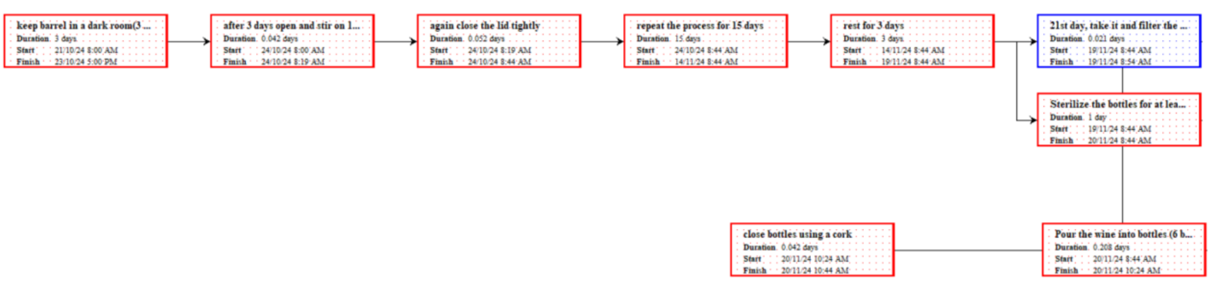


Figure 3

Here the Critical path is: [Keep barrel in a dark room] → [After 3 days open and stir] → [Again close the lid tightly] → [Repeat the process for 15 days] → [Rest for 3 days] → [Sterilize the bottles for atleast one day] → [Pour the wine into bottles] → [close bottles using cork]

Process	Time(days)	Cost
keep barrel in a dark room(3 days)	3	
after 3 days open and stir on 1 direction for 3 - 4 mins	0.0416	
again close the lid tightly	0.052	
repeat the process for 15 days	15	
rest for 3 days	3	
Sterilize the bottles for at least one day	1	600
Pour the wine into bottles	0.208	
close bottles using a cork	0.0416	3000

Critical Time = 3+0.0416+0.052+15+3+1+0.208+0.0416

= 22.3 days = 536.2 hrs

Estimated Cost = Rs 3600

Total Min. Time and Estimation of Cost

With the results obtained, the total critical cost = 1.26 + 0.7258 + 22.3 = 24.28 ~ **25 days**

To calculate the cost, we need to take in the labor and equipment considered for this production. These are listed below

a. Labor(Rs 700/day) = 17500

b. Dehydrator = 5000

c. Grape washer = Rs 100000

d. Crusher = Rs 175000

e. Filtration = Rs 75000

f. Clay barrel = Rs 36500

e. rental facility for fermentation = Rs 10000 per month

Except labor and rent, rest of the things are a one-time cost.

So Cost(without equipment) = 3600 + 17500(Labor) + 10000(rent) = Rs 31100
Therefore, Total estimated Cost = 31100 + [5000+100000+175000+75000+36500](one time cost) = Rs 422600

5. Conclusion

This project analyzed the wine production process for scaling up to 600 bottles, focusing on both operational efficiency and cost-effectiveness. By utilizing a neural network to predict ingredient quantities and the Critical Path Method (CPM) to optimize time and resource allocation, we developed a comprehensive plan across three key phases: Collecting Ingredients, Assembling Ingredients, and Fermentation. The neural network enabled precise ingredient estimation, while CPM helped minimize the production timeline, reducing it to approximately 25 days.

The total production cost, considering labor, facility rental, and essential equipment, was estimated at ₹4,22,600. This includes both recurring costs, such as labor and rent, and one-time equipment investments. The analysis identified critical tasks that directly impact the overall timeline, ensuring that resources are allocated efficiently to achieve the production goals within the shortest possible time.

In summary, the project confirms that scaling up wine production to 600 bottles is feasible within a timeline of 25 days, supported by ingredient predictions and cost-effective planning. This structured approach offers a clear path for the client to manage future expansions and maintain both operational efficiency and financial control.

6. Limitations of the Study

The limitations are given below:

- **Market Data Accuracy**: The use of average prices from websites instead of obtaining accurate, local market data introduces uncertainty in both time and cost calculations, making budget projections potentially inaccurate.
- **Scaling Assumptions**: The assumption that ingredient quantities, labor, and equipment usage scale linearly with production volume might not hold in practice, leading to inefficiencies or higher-than-expected resource usage during larger production runs.
- **Labor Efficiency**: The impact of adding labor without accounting for human factors like fatigue, skill variability, and equipment management efficiency could lead to discrepancies between the estimated and actual production time.

7. Future Scope

The current project, which focuses on optimising the wine production process through the Critical Path Method (CPM), provides a foundation for streamlining operations and managing resource allocation in the transition from small-scale to large-scale production. However, there are several avenues for future exploration and improvement that can further enhance the efficiency and scalability of wine production:

- **Integration of Advanced Optimisation Techniques**: While CPM is a robust tool for identifying critical activities, future research could incorporate more sophisticated optimisation techniques such as Linear Programming (LP) or Dynamic Programming to optimise resource allocation, minimise costs, and improve scheduling flexibility. These methods could help in solving more complex production challenges, especially when dealing with variable demand or multiple production facilities.
- **Incorporation of Stochastic Models**: In real-world scenarios, uncertainties such as weather conditions, equipment malfunctions, or labor shortages can affect wine production timelines. Future studies could integrate stochastic models or Monte Carlo simulations into the analysis to account for these uncertainties and develop more resilient production plans that minimise risk and delays.
- **Exploration of Sustainable Production Practices**: As the wine industry increasingly adopts sustainable practices, future research could explore how CPM can be adapted to incorporate environmentally friendly production methods. This could involve optimising energy consumption, water usage, and waste management throughout the production process, ensuring that scaling up does not compromise sustainability goals.
- **Application to Multiple Production Sites**: As the production scales beyond a single facility, future research could explore how CPM can be applied to coordinate operations across multiple production sites. This would involve developing models to manage the logistics of supply chains, transportation, and inventory control, while ensuring that quality standards are maintained across all locations.
- **Automation and Technology Integration**: Future projects could explore the role of automation and technology in further optimising wine production processes. The integration of sensors, IoT (Internet of Things), and AI-driven predictive analytics could provide real-time data for better decision-making, allowing for dynamic adjustment of the production schedule based on current conditions.
- **Expansion to Different Wine Varieties**: This project focuses on a single production process; future research could expand the scope to different wine varieties that require unique production timelines and processes, such as sparkling wines or aged reds. Analysing how CPM applies across various wine types could provide more comprehensive insights into improving production efficiencies in different segments of the wine industry.

By addressing these potential future directions, the research can contribute to more innovative, sustainable, and scalable wine production processes, benefiting both producers and consumers in a competitive market.

8. References

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9. Appendix

Interpolation Python Code

```
import numpy as np
from scipy.interpolate import interp1d

# Known data points for interpolation including predicted values
bottles = np.array([1,6,50
                    ])
quantity = np.array([#Enter respective quantity
])

# Create a linear interpolation function
interpolation_function = interp1d(bottles, quantity, kind='linear',
fill_value='extrapolate')

# Predicting values for bottles 7 to 20
predicted_bottles = np.arange(1,51)
predicted_quantity = interpolation_function(predicted_bottles)

# Output the predicted values
for bottle, quantity in zip(predicted_bottles, predicted_quantity):
    print(f'Predicted quantity for {bottle} bottles: {quantity}')
```

Neural Network Code

```
import numpy as np
import matplotlib.pyplot as plt
from sklearn.model_selection import train_test_split
from sklearn.preprocessing import MinMaxScaler
from keras.models import Sequential
from keras.layers import Dense
import random
import tensorflow as tf

# Interpolated data for grapes from 1 to 50 bottles
bottles = np.array([1, 2, 3, 4, 5, 6, 7, 8, 9, 10,
                    11, 12, 13, 14, 15, 16, 17, 18, 19, 20,
                    21, 22, 23, 24, 25, 26, 27, 28, 29, 30,
                    31, 32, 33, 34, 35, 36, 37, 38, 39, 40,
                    41, 42, 43, 44, 45, 46, 47, 48, 49, 50])
grape_quantities = np.array([#Enter the interpolated Values
```

```
])

# Reshape data for model
X = bottles.reshape(-1, 1)  # Features
y = grape_quantities.reshape(-1, 1)  # Target

# Scale the data
scaler_X = MinMaxScaler()
scaler_y = MinMaxScaler()
X_scaled = scaler_X.fit_transform(X)
y_scaled = scaler_y.fit_transform(y)

# Split data into training and testing sets
X_train, X_test, y_train, y_test = train_test_split(X_scaled, y_scaled,
test_size=0.2, random_state=42)

seed_value = 42
random.seed(seed_value)
np.random.seed(seed_value)
tf.random.set_seed(seed_value)

# Function to create, compile, and train a new model
def create_and_train_model(X_train, y_train):
    model = Sequential()
    model.add(Dense(10, activation='relu', input_shape=(1,)))  # First hidden
layer with 10 neurons
    model.add(Dense(5, activation='relu'))  # Second hidden layer with 5 neurons
    model.add(Dense(1))  # Output layer
    model.compile(optimizer='adam', loss='mean_squared_error', metrics=['mse'])

    # Train the model and save training history
    history = model.fit(X_train, y_train, epochs=300, batch_size=5,
validation_split=0.2, verbose=0)

    return model, history

# Function to get the best model and its prediction
def get_best_model_and_prediction(input_data, num_predictions=5):
    best_model = None
    best_mse = float('inf')
    best_prediction = None
    best_history = None

    for i in range(num_predictions):
        # Create and train a new model for each prediction
```

```
        model, history = create_and_train_model(X_train, y_train)

        # Make a prediction
        y_pred_scaled = model.predict(input_data)
        prediction = scaler_y.inverse_transform(y_pred_scaled)[0][0]

        # Calculate MSE on the test set
        y_test_pred_scaled = model.predict(X_test)
        mse = np.mean((scaler_y.inverse_transform(y_test_pred_scaled) -
scaler_y.inverse_transform(y_test))**2)

        # Check if this model is the best so far
        if mse < best_mse:
            best_mse = mse
            best_model = model
            best_prediction = prediction
            best_history = history  # Save the best history for plotting later

        # Plot the fitted model
        y_pred_scaled_all = model.predict(X_scaled)
        y_pred_all = scaler_y.inverse_transform(y_pred_scaled_all)

        plt.figure(figsize=(10, 6))
        plt.scatter(bottles, grape_quantities, color='blue', label='Original
Data', s=50)
        plt.plot(bottles, y_pred_all, color='red', label=f'Fitted Model after
Prediction {i + 1}', linewidth=2)
        plt.title(f'Neural Network Fit - Prediction {i + 1} (MSE: {mse:.4f})')
        plt.xlabel('Number of Bottles')
        plt.ylabel(' Quantity ')
        plt.legend()
        plt.grid(True)
        plt.show()

    return best_model, best_prediction, best_history

# Predict for a specific number of bottles (600 in this case)
input_data = scaler_X.transform(np.array([[600]]))
best_model, final_prediction, best_history =
get_best_model_and_prediction(input_data)

# Print the final prediction
print(f'Final predicted quantity for 600 bottles using the best fitted model:
{final_prediction:.2f} ')
```

```python
# Final Plot with the best model
y_pred_scaled = best_model.predict(X_scaled)
y_pred = scaler_y.inverse_transform(y_pred_scaled)

plt.figure(figsize=(10, 6))
plt.scatter(bottles, grape_quantities, color='blue', label='Original Data', s=50)
plt.plot(bottles, y_pred, color='green', label='Best Fitted Model', linewidth=2)
plt.title('Final Neural Network Fit for Quantity Prediction (Best Model)')
plt.xlabel('Number of Bottles')
plt.ylabel('Grape Quantity (kg)')
plt.legend()
plt.grid(True)
plt.show()

# Plot training vs validation loss for the best model ONLY ONCE
plt.figure(figsize=(10, 6))
plt.plot(best_history.history['loss'], label='Training Loss')
plt.plot(best_history.history['val_loss'], label='Validation Loss')
plt.title('Training vs Validation Loss for Best Fitted Model')
plt.xlabel('Epochs')
plt.ylabel('Loss')
plt.legend()
plt.grid(True)
plt.show()
```