

OPRE 607 Final Project

November 15, 2025

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[1]: #!/usr/bin/env python
"""
OPRE 607 - Business Analytics Final Project
Title: Portfolio Optimization for Tech Sector Investment

BUSINESS PROBLEM:
An investment firm managing a $10 million technology sector portfolio needs to
optimize asset allocation across 7 major tech stocks to maximize risk-adjusted
returns while adhering to diversification constraints and risk management
policies.

"""

import numpy as np
import pandas as pd
import yfinance as yf
import pandas_datareader as pdr
from datetime import datetime, timedelta
import matplotlib.pyplot as plt
import seaborn as sns
from matplotlib.gridspec import GridSpec
from matplotlib.ticker import FuncFormatter
from scipy.optimize import minimize
from sklearn.linear_model import LinearRegression
from sklearn.decomposition import PCA
import warnings
from openpyxl import Workbook
from openpyxl.utils import get_column_letter
from openpyxl.styles import Font, PatternFill, Alignment, Border, Side,
    NamedStyle
from openpyxl.chart import ScatterChart, Reference, Series, BarChart, LineChart
from openpyxl.worksheet.table import Table, TableStyleInfo
from openpyxl.worksheet.datavalidation import DataValidation
from openpyxl.workbook.defined_name import DefinedName

warnings.filterwarnings('ignore')
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# Professional color scheme for visualizations
PORTFOLIO_COLORS = {
    'primary': '003f5c',
    'secondary': '58508d',
    'accent': 'bc5090',
    'success': 'ff6361',
    'warning': 'ffa600',
    'neutral': '7a5195',
    'light': 'F6F7F8',
    'dark': '2D3436',
    'table_header': '003f5c',
    'table_row1': 'f0f4f7',
    'table_row2': 'FFFFFF'
}

# Matplotlib configuration for professional charts
plt.style.use('seaborn-v0_8-whitegrid')
sns.set_context("notebook", font_scale=0.85)
plt.rcParams.update({
    'figure.dpi': 100,
    'savefig.dpi': 300,
    'font.size': 8,
    'axes.labelsize': 9,
    'axes.titlesize': 11,
    'xtick.labelsize': 7,
    'ytick.labelsize': 7,
    'legend.fontsize': 7,
    'figure.titlesize': 13,
    'axes.titlepad': 12,
    'axes.labelpad': 8
})

class EnhancedPortfolioOptimizer:
    """
    Comprehensive portfolio optimization engine implementing multiple asset pricing models.

    Models Implemented:
    - Markowitz Mean-Variance Optimization
    - Arbitrage Pricing Theory (APT)
    - Monte Carlo Simulation
    - Fama-French Factor Models (3-factor and 5-factor)
    - Carhart 4-factor Model
    """
    def __init__(self, tickers, start_date='2020-01-01', end_date=None):

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"""Initialize portfolio optimizer with stock tickers and date range."""
self.tickers = tickers
self.start_date = start_date

if end_date is None:
    self.end_date = datetime.now().strftime('%Y-%m-%d')
else:
    self.end_date = end_date

self.model_params = {
    'initial_investment': 10000000,      # $10 million portfolio
    'risk_free_rate': 0.04,        # 4% annual risk-free rate (US Treasury)
    'transaction_cost': 0.001,       # 0.1% transaction cost
    'confidence_level': 0.95,        # 95% confidence for risk metrics
    'trading_days': 252,           # Standard trading days per year
    'min_investment': 0.01,         # Minimum 1% position size
    'max_investment': 0.30,         # Maximum 30% position size
    ↵(diversification)
    'target_return_cap': 0.30,      # Cap returns at 30% (realistic for
    ↵tech)
    'max_volatility': 0.35,        # Maximum 35% portfolio volatility
    'min_stocks_active': 7          # Minimum 7 stocks for diversification
}

# Storage for different model results
self.models = {
    'markowitz': {},
    'apt': {},
    'ff3': {},
    'ff5': {},
    'carhart': {},
    'monte_carlo': {}
}

self.factor_data = {}
self.factor_loadings = {}
self.sensitivity_results = pd.DataFrame()
self.what_if_scenarios = {}

def fetch_all_data(self):
    """
    Main data pipeline: Fetch real prices from Yahoo Finance and factor
    ↵data.
    """
    print("Fetching real market data...")

    # Fetch real stock prices from Yahoo Finance

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        self.fetch_real_stock_data()

    # Validate data quality
    self.validate_data_quality()

    # Fetch real Fama-French factors
    self.fetch_real_fama_french_factors()

    # Fetch real macro factors
    self.fetch_real_macro_factors()

    # Calculate factor loadings
    self.calculate_factor_loadings()

    print("Real data preparation complete!")
    return True

def fetch_real_stock_data(self):
    """
    Fetch real stock price data from Yahoo Finance.
    """
    print("  Downloading real stock prices from Yahoo Finance...")

    try:
        # Download real stock data
        raw_data = yf.download(
            self.tickers,
            start=self.start_date,
            end=self.end_date,
            progress=False
        )

        # Extract adjusted close prices
        if isinstance(raw_data.columns, pd.MultiIndex):
            if 'Adj Close' in raw_data.columns.levels[0]:
                self.prices = raw_data['Adj Close']
            else:
                self.prices = raw_data['Close']
        else:
            self.prices = raw_data[['Adj Close']] if 'Adj Close' in \
raw_data.columns else raw_data

        # Ensure we have data for all tickers
        if isinstance(self.prices, pd.Series):
            self.prices = pd.DataFrame(self.prices)

        # Forward fill missing data (holidays, etc.)
    
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        self.prices = self.prices.ffill()

        missing_tickers = [t for t in self.tickers if t not in self.prices.
columns]
        if missing_tickers:
            print(f"  WARNING: Could not fetch data for: {', '.
join(missing_tickers)}")
            # Filter out missing tickers from our list
            self.tickers = [t for t in self.tickers if t in self.prices.
columns]

        # Calculate returns
        self.returns = self.prices.pct_change().dropna()

        # Remove any remaining NaN values
        self.returns = self.returns.dropna()

        # Calculate statistics
        self.expected_returns = self.returns.mean() * self.
model_params['trading_days']
        self.cov_matrix = self.returns.cov() * self.
model_params['trading_days']
        self.corr_matrix = self.returns.corr()

        print(f"  Downloaded {len(self.prices)} days of real price data for\u
{len(self.tickers)} stocks")
        print(f"  Date range: {self.prices.index[0].date()} to {self.prices.
index[-1].date()}")

        # Display actual returns for validation
print("\n  Actual Annual Expected Returns:")
for ticker in self.tickers:
    if ticker in self.expected_returns:
        print(f"    {ticker}: {self.expected_returns[ticker]:.2%}")

except Exception as e:
    print(f"  Error fetching real data: {e}")

def fetch_real_fama_french_factors(self):
    """
    Fetch real Fama-French factors from Ken French's data library.
    """
    print("  Fetching real Fama-French factors...")

    try:
        # Fetch Fama-French 3-factor data

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ff3_data_dict = pdr.get_data_famafrance(
    'F-F_Research_Data_Factors_daily',
    start=self.start_date,
    end=self.end_date
)

if ff3_data_dict and 0 in ff3_data_dict:
    ff3_data = ff3_data_dict[0]
    # Convert to decimal format
    ff3_data = ff3_data / 100.0
    ff3_data.index = pd.to_datetime(ff3_data.index)

    # Align with stock data dates
    common_dates = self.returns.index.intersection(ff3_data.index)
    self.factor_data['ff3'] = ff3_data.loc[common_dates]
else:
    print("    Could not fetch FF3 data.")

# Fetch Fama-French 5-factor data
ff5_data_dict = pdr.get_data_famafrance(
    'F-F_Research_Data_5_Factors_2x3_daily',
    start=self.start_date,
    end=self.end_date
)

if ff5_data_dict and 0 in ff5_data_dict:
    ff5_data = ff5_data_dict[0]
    ff5_data = ff5_data / 100.0
    ff5_data.index = pd.to_datetime(ff5_data.index)
    common_dates = self.returns.index.intersection(ff5_data.index)
    self.factor_data['ff5'] = ff5_data.loc[common_dates]
else:
    print("    Could not fetch FF5 data.")

# Fetch momentum factor
mom_data_dict = pdr.get_data_famafrance(
    'F-F_Momentum_Factor_daily',
    start=self.start_date,
    end=self.end_date
)

if mom_data_dict and 0 in mom_data_dict:
    mom_data = mom_data_dict[0]
    mom_data = mom_data / 100.0
    mom_data.index = pd.to_datetime(mom_data.index)
    common_dates = self.returns.index.intersection(mom_data.index)
    self.factor_data['momentum'] = mom_data.loc[common_dates]

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        else:
            print("    Could not fetch Momentum data.")

        print(f"  Downloaded real Fama-French factors")

    except Exception as e:
        print(f"  Error fetching Fama-French data: {e}")

def fetch_real_macro_factors(self):
    """
    Fetch real macroeconomic factors for APT model.
    Using market indices as proxies for macro factors.
    """
    print("  Fetching real macro factors for APT...")

    try:
        # Define macro factor proxies
        macro_tickers = {
            '^VIX': 'Volatility',      # VIX for market volatility
            '^TNX': 'Interest_Rate',   # 10-year Treasury yield
            'DX-Y.NYB': 'Dollar_Index', # US Dollar Index
            'GLD': 'Gold',             # Gold as inflation hedge
            'XLE': 'Energy'            # Energy sector ETF
        }

        # Download macro data
        macro_data = yf.download(
            list(macro_tickers.keys()),
            start=self.start_date,
            end=self.end_date,
            progress=False
        )

        # Extract adjusted close prices
        if isinstance(macro_data.columns, pd.MultiIndex):
            macro_prices = macro_data['Adj Close'] if 'Adj Close' in \
macro_data.columns.levels[0] else macro_data['Close']
        else:
            macro_prices = macro_data

        # Rename columns
        macro_prices.columns = [macro_tickers.get(col, col) for col in \
macro_prices.columns]

        # Calculate returns
        macro_returns = macro_prices.pct_change().dropna()
    
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# Align with stock data
common_dates = self.returns.index.intersection(macro_returns.index)
self.factor_data['macro'] = macro_returns.loc[common_dates]

    print(f"  Downloaded real macro factors ({len(common_dates)}) observations")

except Exception as e:
    print(f"  Error fetching macro data: {e}")

def save_data_to_excel(self, filename="Portfolio_Data.xlsx"):
    """
    Save fetched and computed data (prices, returns, expected returns,
    covariances, etc.)
    to Excel file.
    """
    print(f"Saving portfolio data to Excel: {filename}")

    wb = Workbook()
    ws_prices = wb.active
    ws_prices.title = "Prices"

    # --- Prices ---
    ws_prices.append(["Date"] + list(self.prices.columns))
    for date, row in self.prices.iterrows():
        ws_prices.append([date.strftime("%Y-%m-%d")] + list(row.values))

    # --- Returns ---
    ws_returns = wb.create_sheet("Returns")
    ws_returns.append(["Date"] + list(self.returns.columns))
    for date, row in self.returns.iterrows():
        ws_returns.append([date.strftime("%Y-%m-%d")] + list(row.values))

    # --- Expected Returns ---
    ws_exp = wb.create_sheet("Expected Returns")
    ws_exp.append(["Ticker", "Annual Expected Return"])
    for ticker, val in self.expected_returns.items():
        ws_exp.append([ticker, val])

    # --- Covariance Matrix ---
    ws_cov = wb.create_sheet("Covariance Matrix")
    ws_cov.append([""] + list(self.cov_matrix.columns))
    for ticker, row in self.cov_matrix.iterrows():
        ws_cov.append([ticker] + list(row.values))

    # --- Correlation Matrix ---
    ws_corr = wb.create_sheet("Correlation Matrix")

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ws_corr.append([""] + list(self.corr_matrix.columns))
for ticker, row in self.corr_matrix.iterrows():
    ws_corr.append([ticker] + list(row.values))

# --- Fama-French Factors (if available) ---
if 'ff3' in self.factor_data:
    ws_ff3 = wb.create_sheet("FF3 Factors")
    ff3_df = self.factor_data['ff3']
    ws_ff3.append(["Date"] + list(ff3_df.columns))
    for date, row in ff3_df.iterrows():
        ws_ff3.append([date.strftime("%Y-%m-%d")] + list(row.values))

# --- Macro Factors (if available) ---
if 'macro' in self.factor_data:
    ws_macro = wb.create_sheet("Macro Factors")
    macro_df = self.factor_data['macro']
    ws_macro.append(["Date"] + list(macro_df.columns))
    for date, row in macro_df.iterrows():
        ws_macro.append([date.strftime("%Y-%m-%d")] + list(row.values))

# --- Basic Styling ---
for sheet in wb.sheetnames:
    ws = wb[sheet]
    for col in ws.columns:
        max_length = max(len(str(cell.value)) for cell in col if cell.
        value is not None)
        ws.column_dimensions[get_column_letter(col[0].column)].width = max(12, max_length + 2)
    ws.freeze_panes = "B2"

wb.save(filename)
print(f"Data successfully saved to '{filename}'")

def validate_data_quality(self):
    """
    Data quality check: Validate and clean real data.
    """
    print(" Validating data quality...")

    # Check for missing data
    missing_pct = self.returns.isnull().sum() / len(self.returns) * 100
    for ticker in self.tickers:
        if ticker in missing_pct and missing_pct[ticker] > 5:
            print(f" {ticker}: {missing_pct[ticker]:.1f}% missing data")

    # Check for extreme returns
    for ticker in self.tickers:

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        if ticker in self.returns.columns:
            daily_returns = self.returns[ticker]
            extreme_returns = daily_returns[abs(daily_returns) > 0.20]
            if len(extreme_returns) > 0:
                print(f" {ticker}: {len(extreme_returns)} days with >20%↑
↪daily moves")

    # Cap unrealistic annual returns
    for ticker in self.tickers:
        if ticker in self.expected_returns:
            annual_return = self.expected_returns[ticker]
            if annual_return > self.model_params['target_return_cap']:
                print(f"    Capping {ticker} return at {self.
↪model_params['target_return_cap']:.1%} (was {annual_return:.1%})")
                self.expected_returns[ticker] = self.
↪model_params['target_return_cap']
            elif annual_return < -0.30:
                print(f"    Flooring {ticker} return at -30% (was_
↪{annual_return:.1%})")
                self.expected_returns[ticker] = -0.30

    print("  Data validation complete")

def calculate_factor_loadings(self):
    """
    Calculate factor exposures (betas) for each stock using regression.
    """
    print("Calculating factor loadings...")
    dates = self.returns.index

    self.calculate_ff3_loadings(dates)
    self.calculate_ff5_loadings(dates)
    self.calculate_carhart_loadings(dates)
    self.calculate_apt_loadings(dates)
    self.calculate_statistical_factors()

    print("Factor loadings calculated!")

def calculate_ff3_loadings(self, dates):
    """Calculate Fama-French 3-factor loadings."""
    self.factor_loadings['ff3'] = pd.DataFrame(index=self.tickers)
    self.factor_loadings['ff3_stats'] = pd.DataFrame(index=self.tickers)

    if 'ff3' not in self.factor_data:
        return

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for ticker in self.tickers:
    if ticker not in self.returns.columns:
        continue

try:
    # Get aligned data
    common_dates = dates.intersection(self.factor_data['ff3'].index)
    y = self.returns[ticker].loc[common_dates]
    ff_data = self.factor_data['ff3'].loc[common_dates]

    X = ff_data[['Mkt-RF', 'SMB', 'HML']]
    rf = ff_data['RF'] if 'RF' in ff_data.columns else 0
    y_excess = y - rf

    # Remove NaN values
    valid_idx = ~(y_excess.isna() | X.isna().any(axis=1))
    y_clean = y_excess[valid_idx]
    X_clean = X[valid_idx]

    if len(y_clean) > 30:
        model = LinearRegression()
        model.fit(X_clean, y_clean)

        self.factor_loadings['ff3'].loc[ticker, 'Alpha'] = model.
        ↪intercept_ * 252
        self.factor_loadings['ff3'].loc[ticker, 'Mkt-RF'] = model.
        ↪coef_[0]
        self.factor_loadings['ff3'].loc[ticker, 'SMB'] = model.
        ↪coef_[1]
        self.factor_loadings['ff3'].loc[ticker, 'HML'] = model.
        ↪coef_[2]

    # Calculate R-squared
    y_pred = model.predict(X_clean)
    ss_res = np.sum((y_clean - y_pred) ** 2)
    ss_tot = np.sum((y_clean - np.mean(y_clean)) ** 2)
    r_squared = 1 - (ss_res / ss_tot) if ss_tot > 0 else 0
    self.factor_loadings['ff3_stats'].loc[ticker, 'R2'] =
    ↪r_squared

except Exception as e:
    print(f"    Could not calculate FF3 loadings for {ticker}: {e}")

def calculate_ff5_loadings(self, dates):
    """Calculate Fama-French 5-factor loadings."""
    self.factor_loadings['ff5'] = pd.DataFrame(index=self.tickers)
    self.factor_loadings['ff5_stats'] = pd.DataFrame(index=self.tickers)

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if 'ff5' not in self.factor_data:
    return

for ticker in self.tickers:
    if ticker not in self.returns.columns:
        continue

try:
    common_dates = dates.intersection(self.factor_data['ff5'].index)
    y = self.returns[ticker].loc[common_dates]
    ff_data = self.factor_data['ff5'].loc[common_dates]

    X = ff_data[['Mkt-RF', 'SMB', 'HML', 'RMW', 'CMA']]
    rf = ff_data['RF'] if 'RF' in ff_data.columns else 0
    y_excess = y - rf

    valid_idx = ~(y_excess.isna() | X.isna().any(axis=1))
    y_clean = y_excess[valid_idx]
    X_clean = X[valid_idx]

    if len(y_clean) > 30:
        model = LinearRegression()
        model.fit(X_clean, y_clean)

        self.factor_loadings['ff5'].loc[ticker, 'Alpha'] = model.
        ↪intercept_ * 252
        for i, col in enumerate(X.columns):
            self.factor_loadings['ff5'].loc[ticker, col] = model.
        ↪coef_[i]

        y_pred = model.predict(X_clean)
        ss_res = np.sum((y_clean - y_pred) ** 2)
        ss_tot = np.sum((y_clean - np.mean(y_clean)) ** 2)
        r_squared = 1 - (ss_res / ss_tot) if ss_tot > 0 else 0
        self.factor_loadings['ff5_stats'].loc[ticker, 'R2'] =
        ↪r_squared

    except Exception as e:
        print(f"    Could not calculate FF5 loadings for {ticker}: {e}")

def calculate_carhart_loadings(self, dates):
    """Calculate Carhart 4-factor loadings."""
    self.factor_loadings['carhart'] = pd.DataFrame(index=self.tickers)
    self.factor_loadings['carhart_stats'] = pd.DataFrame(index=self.
    ↪tickers) # Added for R2

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if 'ff3' not in self.factor_data or 'momentum' not in self.factor_data:
    return

for ticker in self.tickers:
    if ticker not in self.returns.columns:
        continue

try:
    common_dates = dates.intersection(self.factor_data['ff3'].index)
    common_dates = common_dates.intersection(self.
    ↪factor_data['momentum'].index)

    y = self.returns[ticker].loc[common_dates]
    ff_data = self.factor_data['ff3'].loc[common_dates]
    mom_data = self.factor_data['momentum'].loc[common_dates]

    X = pd.concat([ff_data[['Mkt-RF', 'SMB', 'HML']], ↪
    ↪mom_data[['Mom']]], axis=1)
    rf = ff_data['RF'] if 'RF' in ff_data.columns else 0
    y_excess = y - rf

    valid_idx = ~(y_excess.isna() | X.isna().any(axis=1))
    y_clean = y_excess[valid_idx]
    X_clean = X[valid_idx]

    if len(y_clean) > 30:
        model = LinearRegression()
        model.fit(X_clean, y_clean)

        self.factor_loadings['carhart'].loc[ticker, 'Alpha'] = ↪
    ↪model.intercept_ * 252
        for i, col in enumerate(X.columns):
            self.factor_loadings['carhart'].loc[ticker, col] = ↪
    ↪model.coef_[i]

        # Calculate R-squared
        y_pred = model.predict(X_clean)
        ss_res = np.sum((y_clean - y_pred) ** 2)
        ss_tot = np.sum((y_clean - np.mean(y_clean)) ** 2)
        r_squared = 1 - (ss_res / ss_tot) if ss_tot > 0 else 0
        self.factor_loadings['carhart_stats'].loc[ticker, 'R2'] = ↪
    ↪r_squared

    except Exception as e:
        print(f"    Could not calculate Carhart loadings for {ticker}: {e}")

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def calculate_apt_loadings(self, dates):
    """Calculate APT factor loadings using macro factors."""
    self.factor_loadings['apt'] = pd.DataFrame(index=self.tickers)
    self.factor_loadings['apt_stats'] = pd.DataFrame(index=self.tickers)

    if 'macro' not in self.factor_data:
        return

    for ticker in self.tickers:
        if ticker not in self.returns.columns:
            continue

        try:
            common_idx = self.returns.index.intersection(self.
                ↪factor_data['macro'].index)

            if len(common_idx) > 30:
                y_aligned = self.returns[ticker].loc[common_idx]
                X_aligned = self.factor_data['macro'].loc[common_idx]

                valid_idx = ~(y_aligned.isna() | X_aligned.isna()).
                    ↪any(axis=1))
                y_clean = y_aligned[valid_idx]
                X_clean = X_aligned[valid_idx]

                if len(y_clean) > 30:
                    model = LinearRegression()
                    model.fit(X_clean, y_clean)

                    self.factor_loadings['apt'].loc[ticker, 'Alpha'] = ↪
                    ↪model.intercept_ * 252
                    for i, factor in enumerate(X_clean.columns):
                        self.factor_loadings['apt'].loc[ticker, factor] = ↪
                    ↪model.coef_[i]

                    y_pred = model.predict(X_clean)
                    ss_res = np.sum((y_clean - y_pred) ** 2)
                    ss_tot = np.sum((y_clean - np.mean(y_clean)) ** 2)
                    r_squared = 1 - (ss_res / ss_tot) if ss_tot > 0 else 0
                    self.factor_loadings['apt_stats'].loc[ticker, 'R2'] = ↪
                    ↪r_squared

            except Exception as e:
                print(f"    Could not calculate APT loadings for {ticker}: {e}")

    def calculate_statistical_factors(self):

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"""Use Principal Component Analysis (PCA) to extract statistical
↳factors."""
try:
    returns_clean = self.returns.dropna()

    if len(returns_clean) > 0 and len(returns_clean.columns) > 0:
        # Standardize returns
        returns_std = (returns_clean - returns_clean.mean()) / ↳
↳returns_clean.std()

        # Apply PCA
        n_components = min(3, len(self.tickers))
        pca = PCA(n_components=n_components)
        factors = pca.fit_transform(returns_std)

        self.factor_data['statistical'] = pd.DataFrame(
            factors,
            index=returns_clean.index,
            columns=[f'PC{i+1}' for i in range(factors.shape[1])]
        )

        self.factor_loadings['statistical'] = pd.DataFrame(
            pca.components_.T,
            index=self.tickers if len(self.tickers) == returns_clean.
↳shape[1] else returns_clean.columns,
            columns=[f'PC{i+1}' for i in range(pca.n_components_)]
        )

        self.factor_loadings['statistical_variance'] = pca.
↳explained_variance_ratio_

        print(f" Extracted {pca.n_components_} principal components")
        print(f" Explained variance: {pca.explained_variance_ratio_.
↳round(3)}")

    except Exception as e:
        print(f" Could not calculate statistical factors: {e}")

def optimize_markowitz_enhanced(self):
    """
    Enhanced Markowitz mean-variance optimization.
    """
    print("Running Markowitz optimization...")
    n = len(self.tickers)

    # Ensure valid data
    if self.cov_matrix.empty or self.expected_returns.empty:

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        print(" Insufficient data for optimization")
        return None

    # Minimize portfolio variance
    def objective(weights):
        portfolio_variance = np.dot(weights.T, np.dot(self.cov_matrix.
values, weights))
        # Add small penalty for concentration
        concentration_penalty = 0.01 * np.sum(weights**2)
        return portfolio_variance + concentration_penalty

    # Initial guess: equal weights
    x0 = np.ones(n) / n

    # Bounds: between min and max investment
    bounds = tuple((self.model_params['min_investment'],
                    self.model_params['max_investment'])) for _ in range(n))

    # Constraints
    constraints = [
        {'type': 'eq', 'fun': lambda x: np.sum(x) - 1},
        {'type': 'ineq', 'fun': lambda x: np.dot(self.expected_returns.
values, x) - 0.10} # Min 10% return
    ]

    # Optimize
    result = minimize(
        objective,
        x0,
        method='SLSQP',
        bounds=bounds,
        constraints=constraints,
        options={'disp': False, 'maxiter': 1000}
    )

    if result.success:
        weights = result.x
        self.models['markowitz']['optimal_weights'] = weights
        self.models['markowitz']['expected_return'] = np.dot(self.
expected_returns.values, weights)
        self.models['markowitz']['volatility'] = np.sqrt(result.fun)

        print(f" Markowitz optimization successful")
        print(f" Expected return: {self.
models['markowitz']['expected_return']:.2%}")
        print(f" Volatility: {self.models['markowitz']['volatility']:.2%}")

```

```

        return weights
    else:
        print(f" Markowitz optimization failed: {result.message}")
        return None

def optimize_apt_enhanced(self, target_return=0.15):
    """
    APT-based portfolio optimization using macro factors.
    """
    print(f"Running APT optimization (target: {target_return:.1%})...")

    n = len(self.tickers)

    # Objective: Minimize risk with diversification
    def objective(weights):
        portfolio_variance = np.dot(weights.T, np.dot(self.cov_matrix.
values, weights))
        concentration_penalty = 0.05 * np.sum(weights**2)
        return portfolio_variance + concentration_penalty

    # Initial guess
    x0 = np.ones(n) / n

    # Bounds
    bounds = tuple((self.model_params['min_investment'],
                    self.model_params['max_investment'])) for _ in range(n))

    # Adjust target return if infeasible
    max_possible_return = np.max(self.expected_returns.values)
    if target_return > max_possible_return:
        target_return = max_possible_return * 0.9
        print(f" Adjusted target return to {target_return:.1%}")

    # Constraints
    constraints = [
        {'type': 'eq', 'fun': lambda x: np.sum(x) - 1},
        {'type': 'ineq', 'fun': lambda x: np.dot(self.expected_returns.
values, x) - target_return}
    ]

    # Optimize
    result = minimize(
        objective,
        x0,
        method='SLSQP',
        bounds=bounds,
        constraints=constraints,

```

```

        options={'disp': False, 'maxiter': 1000}
    )

    if result.success:
        weights = result.x
        self.models['apt']['optimal_weights'] = weights
        self.models['apt']['expected_return'] = np.dot(self.
        ↪expected_returns.values, weights)
        self.models['apt']['volatility'] = np.sqrt(weights.T @ self.
        ↪cov_matrix.values @ weights)

        print(f" APT optimization successful")
        print(f" Expected return: {self.models['apt']['expected_return']:.2%}")
        print(f" Volatility: {self.models['apt']['volatility']:.2%}")

        return weights
    else:
        print(f" APT optimization failed")
        return None

def run_monte_carlo_simulation(self, n_simulations=10000):
    """
    Monte Carlo simulation following Chapter 12 methodology.
    """
    print(f"Running Monte Carlo simulation ({n_simulations:,} portfolios...")
    ↪")

    portfolio_returns = []
    portfolio_risks = []
    portfolio_sharpes = []
    all_weights = []

    n = len(self.tickers)
    mu = self.expected_returns.values
    cov = self.cov_matrix.values
    rf = self.model_params['risk_free_rate']

    for i in range(n_simulations):
        # Generate random weights
        weights = np.random.random(n)
        weights /= np.sum(weights)

        # Calculate metrics
        ret = np.dot(mu, weights)
        risk = np.sqrt(np.dot(weights, np.dot(cov, weights))))
        sharpe = (ret - rf) / risk if risk > 0 else 0

```

```

        portfolio_returns.append(ret)
        portfolio_risks.append(risk)
        portfolio_sharpes.append(sharpe)
        all_weights.append(weights)

    # Store results
    self.models['monte_carlo']['returns'] = portfolio_returns
    self.models['monte_carlo']['risks'] = portfolio_risks
    self.models['monte_carlo']['sharpes'] = portfolio_sharpes

    # Find best portfolio
    best_idx = np.argmax(portfolio_sharpes)
    self.models['monte_carlo']['optimal_weights'] = all_weights[best_idx]
    self.models['monte_carlo']['best_return'] = portfolio_returns[best_idx]
    self.models['monte_carlo']['best_risk'] = portfolio_risks[best_idx]
    self.models['monte_carlo']['best_sharpe'] = portfolio_sharpes[best_idx]

    print(f" Simulation complete!")
    print(f" Best Sharpe Ratio: {portfolio_sharpes[best_idx]:.3f}")
    print(f" Return: {portfolio_returns[best_idx]:.2%}")
    print(f" Risk: {portfolio_risks[best_idx]:.2%}")

    # Calculate VaR and CVaR
    portfolio_values = self.model_params['initial_investment'] * (1 + np.
    ↪array(portfolio_returns))
    var_95 = np.percentile(portfolio_values, 5)
    cvar_95 = np.mean([v for v in portfolio_values if v <= var_95])

    print(f"\n Risk Metrics (95% confidence):")
    print(f"    VaR: ${self.model_params['initial_investment'] - var_95:,.0f}")
    print(f"    CVaR: ${self.model_params['initial_investment'] - cvar_95:,.0f}")

    return portfolio_returns, portfolio_risks, portfolio_sharpes

def perform_sensitivity_analysis(self):
    """
    What-If Analysis
    """
    print("Performing sensitivity analysis (What-If scenarios)...")

    target_returns = np.linspace(0.08, 0.25, 10)
    results = []

    for target in target_returns:

```

```

        weights = self.optimize_apt_enhanced(target_return=target)
        if weights is not None:
            port_ret = np.dot(self.expected_returns.values, weights)
            port_risk = np.sqrt(weights.T @ self.cov_matrix.values @
weights)

            results.append({
                'Target': target,
                'Actual_Return': port_ret,
                'Risk': port_risk,
                'Sharpe': (port_ret - self.model_params['risk_free_rate']) /
port_risk,
                'Active_Stocks': int(np.sum(weights > 0.05))
            })

        self.sensitivity_results = pd.DataFrame(results)

        print(f"Analyzed {len(results)} scenarios")
        print("\nSensitivity Results:")
        print(self.sensitivity_results.to_string(float_format=".4f"))

    return self.sensitivity_results

def create_what_if_scenarios(self):
    """
    Create What-If scenarios.
    """
    print("Creating What-If scenarios...")

    scenarios = {
        'Conservative': {'target_return': 0.10, 'description': 'Low risk,',
stable returns'},
        'Moderate': {'target_return': 0.15, 'description': 'Balanced',
risk-return'},
        'Aggressive': {'target_return': 0.20, 'description': 'High risk,',
high return potential'}
    }

    for name, params in scenarios.items():
        weights = self.
optimize_apt_enhanced(target_return=params['target_return'])

        if weights is not None:
            metrics = self.evaluate_portfolio(weights)
            self.what_if_scenarios[name] = {
                'weights': weights,
                'metrics': metrics,

```

```

        'params': params
    }
    print(f" {name}: {metrics['Expected_Return']:.1%} return, □
↳{metrics['Volatility']:.1%} risk")

    return self.what_if_scenarios

def evaluate_portfolio(self, weights):
    """
    Calculate comprehensive portfolio metrics.
    """

    # Calculate portfolio returns series
    portfolio_returns = self.returns @ weights

    metrics = {
        # --- MODIFICATION HERE ---
        # Use the optimizer's (capped) expected returns for consistency
        'Expected_Return': np.dot(self.expected_returns.values, weights),
        # --- END MODIFICATION ---

        'Volatility': portfolio_returns.std() * np.sqrt(252),
        'Sharpe_Ratio': (np.dot(self.expected_returns.values, weights) - □
↳self.model_params['risk_free_rate']) /
                         (portfolio_returns.std() * np.sqrt(252)), # Also □
        ↳use capped return for Sharpe
        'Max_Drawdown': self.calculate_max_drawdown(portfolio_returns),
        'VaR_95': np.percentile(portfolio_returns, 5) * np.sqrt(252), # □
        ↳Annualized VaR
        'CVaR_95': portfolio_returns[portfolio_returns <= np.
        ↳percentile(portfolio_returns, 5)].mean() * np.sqrt(252), # Annualized CVaR
        'Active_Positions': np.sum(weights > 0.05)
    }

    return metrics

def calculate_max_drawdown(self, returns):
    """Calculate maximum drawdown."""
    if isinstance(returns, np.ndarray):
        returns = pd.Series(returns)

    cumulative = (1 + returns).cumprod()
    running_max = cumulative.expanding().max()
    drawdown = (cumulative - running_max) / running_max

    return drawdown.min()

def compare_all_models_enhanced(self):

```

```

"""
Compare all optimization models.
"""

print("Comparing all models...")

results = {}

# Markowitz
weights_markowitz = self.optimize_markowitz_enhanced()
if weights_markowitz is not None:
    results['Markowitz'] = self.evaluate_portfolio(weights_markowitz)

# APT
weights_apt = self.optimize_apt_enhanced(target_return=0.15)
if weights_apt is not None:
    results['APT'] = self.evaluate_portfolio(weights_apt)

# Monte Carlo
if 'optimal_weights' in self.models['monte_carlo']:
    weights_mc = self.models['monte_carlo']['optimal_weights']
    results['Monte_Carlo'] = self.evaluate_portfolio(weights_mc)

comparison_df = pd.DataFrame(results).T

print("\nModel Comparison Results:")
print("=" * 70)
print(comparison_df.to_string(float_format=".4f"))

# Validate results
print("\n" + "=" * 70)
print("VALIDATION CHECKS")
print("=" * 70)

for model_name, metrics in results.items():
    if metrics['Expected_Return'] > 0.50:
        print(f" {model_name}: Return seems high\u2192({metrics['Expected_Return']:.1%})")
    elif metrics['Expected_Return'] < -0.10:
        print(f" {model_name}: Return seems low\u2192({metrics['Expected_Return']:.1%})")
    else:
        print(f" {model_name}: Return is reasonable\u2192({metrics['Expected_Return']:.1%})")

return comparison_df

```

```

def create_master_dashboard(self, filename='Portfolio_Master_Dashboard.
˓→png'):
    """
    Create a single, comprehensive dashboard with all 16 unique plots.
    """
    print("Creating master visualization dashboard...")

    fig = plt.figure(figsize=(24, 24))
    fig.suptitle(
        'Master Portfolio Optimization Dashboard - OPRE 607 Final\u202a
˓→Project\nComprehensive Analysis',
        fontsize=20, fontweight='bold', y=0.98
    )

    # 4x4 Grid
    gs = GridSpec(4, 4, figure=fig, hspace=0.45, wspace=0.3)

    # --- Row 1 ---
    ax1 = fig.add_subplot(gs[0, 0])
    self._plot_efficient_frontier(ax1)

    ax2 = fig.add_subplot(gs[0, 1])
    self._plot_correlation_heatmap(ax2)

    ax3 = fig.add_subplot(gs[0, 2])
    self._plot_optimal_weights(ax3)

    ax4 = fig.add_subplot(gs[0, 3])
    self._plot_historical_performance(ax4)

    # --- Row 2 ---
    ax5 = fig.add_subplot(gs[1, 0])
    self._plot_expected_returns(ax5)

    ax6 = fig.add_subplot(gs[1, 1])
    self._plot_sensitivity_analysis(ax6)

    ax7 = fig.add_subplot(gs[1, 2])
    self._plot_risk_metrics(ax7) # Sharpe Ratios

    ax8 = fig.add_subplot(gs[1, 3])
    self._plot_scenario_risk_metrics(ax8) # VaR/CVaR/Drawdown

    # --- Row 3 ---
    ax9 = fig.add_subplot(gs[2, 0])
    self._plot_return_distribution(ax9) # APT Dist

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```

        ax10 = fig.add_subplot(gs[2, 1])
        self._plot_capm_analysis(ax10) # CAPM Alpha/Beta

        ax11 = fig.add_subplot(gs[2, 2])
        self._plot_portfolio_factor_exposure(ax11) # APT Exposure

        ax12 = fig.add_subplot(gs[2, 3])
        self._plot_model_r_squared(ax12) # R-Squared

        # --- Row 4 ---
        ax13 = fig.add_subplot(gs[3, 0])
        self._plot_factor_loadings_heatmap(ax13) # APT Loadings

        ax14 = fig.add_subplot(gs[3, 1])
        self._plot_ff3_loadings_heatmap(ax14) # FF3 Loadings

        ax15 = fig.add_subplot(gs[3, 2])
        self._plot_ff5_loadings_heatmap(ax15) # FF5 Loadings

        ax16 = fig.add_subplot(gs[3, 3])
        self._plot_carhart_loadings_heatmap(ax16) # Carhart Loadings

    plt.tight_layout(rect=[0, 0.03, 1, 0.96])
    fig.savefig(filename, dpi=300, bbox_inches='tight', facecolor='white')

    print(f"Displaying dashboard...")
    plt.show()
    plt.close()

    return filename

def create_enhanced_dashboard(self, filename='Portfolio_Dashboard.png'):
    """
    Create professional visualization dashboard. (Original Step 6)
    """
    print("Creating visualization dashboard...")

    fig = plt.figure(figsize=(20, 12))
    fig.suptitle(
        'Portfolio Optimization Dashboard - OPRE 607 Final\u202a',
        'Project\nTechnology Sector Investment Strategy',
        fontsize=16, fontweight='bold', y=0.98
    )

    gs = GridSpec(2, 3, figure=fig, hspace=0.3, wspace=0.3)

```

```

# Panel 1: Efficient Frontier
ax1 = fig.add_subplot(gs[0, 0])
self._plot_efficient_frontier(ax1)

# Panel 2: Correlation Heatmap
ax2 = fig.add_subplot(gs[0, 1])
self._plot_correlation_heatmap(ax2)

# Panel 3: Optimal Weights
ax3 = fig.add_subplot(gs[0, 2])
self._plot_optimal_weights(ax3)

# Panel 4: Historical Performance
ax4 = fig.add_subplot(gs[1, 0])
self._plot_historical_performance(ax4)

# Panel 5: Risk Metrics
ax5 = fig.add_subplot(gs[1, 1])
self._plot_risk_metrics(ax5)

# Panel 6: Sensitivity Analysis
ax6 = fig.add_subplot(gs[1, 2])
self._plot_sensitivity_analysis(ax6)

plt.tight_layout(rect=[0, 0.03, 1, 0.96]) # Adjust for suptitle
fig.savefig(filename, dpi=300, bbox_inches='tight', facecolor='white')

print("Displaying dashboard plot...")
plt.show()

plt.close()

return filename

def create_supplemental_dashboard(self, filename='Portfolio_Supplemental_Dashboard.png'):
    """
    Create a second dashboard with more detailed analytical plots.
    """
    fig = plt.figure(figsize=(14, 14))

    gs = GridSpec(3, 2, figure=fig, hspace=0.45, wspace=0.3)

    # Panel 1: Expected Annual Returns
    ax1 = fig.add_subplot(gs[0, 0])
    self._plot_expected_returns(ax1)

```

```

# Panel 2: APT Factor Loadings by Stock
ax2 = fig.add_subplot(gs[0, 1])
self._plot_factor_loadings_heatmap(ax2)

# Panel 3: Portfolio Factor Exposure
ax3 = fig.add_subplot(gs[1, 0])
self._plot_portfolio_factor_exposure(ax3)

# Panel 4: Scenario Risk Metrics
ax4 = fig.add_subplot(gs[1, 1])
self._plot_scenario_risk_metrics(ax4)

# Panel 5: Return Distribution
ax5 = fig.add_subplot(gs[2, 0])
self._plot_return_distribution(ax5)

# Panel 6: Fama-French 3-Factor Loadings
ax6 = fig.add_subplot(gs[2, 1])
self._plot_ff3_loadings_heatmap(ax6)

plt.tight_layout(rect=[0, 0.03, 1, 0.96]) # Adjust for suptitle
fig.savefig(filename, dpi=300, bbox_inches='tight', facecolor='white')

plt.show()
plt.close()

return filename

def create_factor_model_dashboard(self, u
filename='Portfolio_Factor_Dashboard.png'):
    """
    Create a third dashboard dedicated to factor model analysis
    """
    fig = plt.figure(figsize=(14, 18))

    gs = GridSpec(3, 2, figure=fig, hspace=0.5, wspace=0.3)

    # Panel 1: CAPM Analysis (Alpha vs. Beta)
    ax1 = fig.add_subplot(gs[0, 0])
    self._plot_capm_analysis(ax1)

    # Panel 2: APT Factor Loadings
    ax2 = fig.add_subplot(gs[0, 1])
    self._plot_factor_loadings_heatmap(ax2)

    # Panel 3: Fama-French 3-Factor Loadings
    ax3 = fig.add_subplot(gs[1, 0])

```

```

    self._plot_ff3_loadings_heatmap(ax3)

    # Panel 4: Fama-French 5-Factor Loadings
    ax4 = fig.add_subplot(gs[1, 1])
    self._plot_ff5_loadings_heatmap(ax4)

    # Panel 5: Carhart 4-Factor Loadings
    ax5 = fig.add_subplot(gs[2, 0])
    self._plot_carhart_loadings_heatmap(ax5)

    # Panel 6: Model R-Squared Comparison
    ax6 = fig.add_subplot(gs[2, 1])
    self._plot_model_r_squared(ax6)

    plt.tight_layout(rect=[0, 0.03, 1, 0.96])
    fig.savefig(filename, dpi=300, bbox_inches='tight', facecolor='white')

    print("Displaying factor model dashboard plot...")
    plt.show()
    plt.close()

    return filename

def _plot_efficient_frontier(self, ax):
    """Plot efficient frontier from Monte Carlo simulation."""
    ax.set_title('Efficient Frontier (Monte Carlo)', fontsize=11,
    ↪fontweight='bold')

    if 'returns' in self.models['monte_carlo']:
        risks = self.models['monte_carlo']['risks']
        returns = self.models['monte_carlo']['returns']
        sharpes = self.models['monte_carlo']['sharpes']

        # Plot all portfolios
        sc = ax.scatter(risks, returns, c=sharpes, cmap='viridis',
                        s=1, alpha=0.5)

        # Highlight optimal portfolios
        if 'optimal_weights' in self.models['markowitz']:
            w = self.models['markowitz']['optimal_weights']
            ret = self.models['markowitz']['expected_return']
            vol = self.models['markowitz']['volatility']
            ax.scatter(vol, ret, marker='*', s=200,
            ↪c=f"#[PORTFOLIO_COLORS['success']]",
                        edgecolors='black', label='Markowitz', zorder=5)

        if 'optimal_weights' in self.models['apt']:

```

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        w = self.models['apt']['optimal_weights']
        ret = self.models['apt']['expected_return']
        vol = self.models['apt']['volatility']
        ax.scatter(vol, ret, marker='^', s=200, c=f"#${PORTFOLIO_COLORS['primary']}",
                   edgecolors='black', label='APT', zorder=5)

        ax.set_xlabel('Risk (Volatility)')
        ax.set_ylabel('Expected Return')
        ax.legend()
        plt.colorbar(sc, ax=ax, label='Sharpe Ratio')

    def _plot_correlation_heatmap(self, ax):
        """Plot correlation matrix heatmap."""
        ax.set_title('Stock Correlation Matrix', fontsize=11, fontweight='bold')

        sns.heatmap(self.corr_matrix, annot=True, fmt='.2f',
                    cmap='RdBu_r', center=0, ax=ax,
                    square=True, linewidths=1, cbar_kws={'shrink': 0.8})
        ax.set_xlabel('')
        ax.set_ylabel('')

    def _plot_optimal_weights(self, ax):
        """Plot optimal portfolio weights for all models as a grouped bar chart.
        """
        ax.set_title('Optimal Portfolio Weights Comparison', fontsize=11, fontweight='bold')

        plot_data = []

        # 1. Get APT weights
        if 'optimal_weights' in self.models['apt']:
            weights = self.models['apt']['optimal_weights']
            for ticker, weight in zip(self.tickers, weights):
                plot_data.append({'Ticker': ticker, 'Weight': weight, 'Model': 'APT'})

        # 2. Get Markowitz weights
        if 'optimal_weights' in self.models['markowitz']:
            weights = self.models['markowitz']['optimal_weights']
            for ticker, weight in zip(self.tickers, weights):
                plot_data.append({'Ticker': ticker, 'Weight': weight, 'Model': 'Markowitz'})

        # 3. Get Monte Carlo weights
        if 'optimal_weights' in self.models['monte_carlo']:
            weights = self.models['monte_carlo']['optimal_weights']

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```

        for ticker, weight in zip(self.tickers, weights):
            plot_data.append({'Ticker': ticker, 'Weight': weight, 'Model': u
↳ 'Monte_Carlo'})

    if not plot_data:
        ax.text(0.5, 0.5, 'No optimal weights found to plot.',
                horizontalalignment='center', verticalalignment='center')
        return

    df = pd.DataFrame(plot_data)

    palette = {
        'APT': f"#{PORTFOLIO_COLORS['primary']}",
        'Markowitz': f"#{PORTFOLIO_COLORS['success']}",
        'Monte_Carlo': f"#{PORTFOLIO_COLORS['accent']}"
    }

    # Create grouped bar chart
    sns.barplot(data=df, x='Ticker', y='Weight', hue='Model', ax=ax,
                 palette=palette)

    ax.set_ylabel('Weight')
    ax.set_xlabel('Stock')

    # Format Y-axis as percentage
    ax.yaxis.set_major_formatter(FuncFormatter(lambda y, _: f'{y:.0%}'))

    ax.tick_params(axis='x', rotation=45)
    ax.legend(title='Model')

    def _plot_historical_performance(self, ax):
        """Plot historical cumulative returns of optimized vs. equal-weight
        portfolio."""
        ax.set_title('Portfolio Performance vs. Equal-Weight', fontsize=11,
                    fontweight='bold')

        if 'apt' in self.models and 'optimal_weights' in self.models['apt']:
            # Calculate APT portfolio cumulative return
            apt_weights = self.models['apt']['optimal_weights']
            apt_returns = (1 + (self.returns @ apt_weights)).cumprod()
            ax.plot(apt_returns.index, apt_returns, label='APT Optimized
            ↳ Portfolio',
                    color=f"#{PORTFOLIO_COLORS['primary']}", linewidth=2)

            # Calculate Equal Weight portfolio cumulative return
            equal_weight_returns = (1 + self.returns.mean(axis=1)).cumprod()
            ax.plot(equal_weight_returns.index, equal_weight_returns,

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        label='Equal-Weight (1/n) Portfolio',
        color=f"#{PORTFOLIO_COLORS['success']}", linestyle='--')

    ax.set_xlabel('Date')
    ax.set_ylabel('Cumulative Return')
    ax.legend(loc='best', fontsize=7)
    ax.grid(True, alpha=0.3)
else:
    ax.text(0.5, 0.5, 'Run APT optimization to see performance.',
            horizontalalignment='center', verticalalignment='center')

def _plot_risk_metrics(self, ax):
    """Plot risk metrics comparison."""
    ax.set_title('Risk Metrics by Model (Sharpe Ratio)', fontsize=11,
    fontweight='bold')

    models = []
    sharpes = []

    for model_name in ['markowitz', 'apt', 'monte_carlo']:
        if 'optimal_weights' in self.models.get(model_name, {}):
            models.append(model_name.upper())
            weights = self.models[model_name]['optimal_weights']
            metrics = self.evaluate_portfolio(weights)
            sharpes.append(metrics['Sharpe_Ratio'])

    if models:
        colors = [
            f"#{PORTFOLIO_COLORS['success']}",
            f"#{PORTFOLIO_COLORS['primary']}",
            f"#{PORTFOLIO_COLORS['accent']}"
        ]
        bars = ax.bar(models, sharpes, color=colors[:len(models)])
        ax.set_ylabel('Sharpe Ratio')
        ax.set_ylim(0, max(sharpes) * 1.2)

        for bar, val in zip(bars, sharpes):
            ax.text(bar.get_x() + bar.get_width()/2, bar.get_height(),
                    f'{val:.2f}', ha='center', va='bottom')

def _plot_sensitivity_analysis(self, ax):
    """Plot sensitivity analysis results."""
    ax.set_title('Risk vs. Target Return', fontsize=11, fontweight='bold')

    if not self.sensitivity_results.empty:
        ax.plot(self.sensitivity_results['Target'],
                self.sensitivity_results['Risk'],

```

```

        'o-', color=f"#{PORTFOLIO_COLORS['primary']}", linewidth=2, u
        ↵markersize=6)

    ax.set_xlabel('Target Return')
    ax.set_ylabel('Portfolio Risk')
    ax.grid(True, alpha=0.3)

    # Format axes as percentages
    ax.xaxis.set_major_formatter(FuncFormatter(lambda x, p: f'{x:.0%}'))
    ax.yaxis.set_major_formatter(FuncFormatter(lambda x, p: f'{x:.0%}'))

def _plot_expected_returns(self, ax):
    """Plot horizontal bar chart of expected returns."""
    ax.set_title('Expected Annual Returns (Capped at 30%)', fontsize=11, u
    ↵fontweight='bold')
    if not self.expected_returns.empty:
        sorted_returns = self.expected_returns.sort_values()
        bars = ax.barh(sorted_returns.index, sorted_returns.values,
                       color=f"#{PORTFOLIO_COLORS['secondary']}")
        ax.set_xlabel('Return %')
        ax.xaxis.set_major_formatter(FuncFormatter(lambda x, p: f'{x:.0%}'))

        # Add value labels
        for bar in bars:
            width = bar.get_width()
            ax.text(width + 0.01, bar.get_y() + bar.get_height()/2,
                    f'{width:.1%}', ha='left', va='center', fontsize=7)
    else:
        ax.text(0.5, 0.5, 'Expected returns data not available.',
                horizontalalignment='center', verticalalignment='center')

def _plot_factor_loadings_heatmap(self, ax):
    """Plot heatmap of APT factor loadings for each stock."""
    ax.set_title('APT Factor Loadings by Stock', fontsize=11, u
    ↵fontweight='bold')
    if 'apt' in self.factor_loadings and not self.factor_loadings['apt'].empty:
        sns.heatmap(self.factor_loadings['apt'], annot=True, fmt='.2f',
                    cmap='RdBu_r', center=0, ax=ax,
                    linewidths=0.5, cbar_kws={'label': 'Factor Loading'})
        ax.set_xlabel('Macro-Economic Factors')
        ax.set_ylabel('Stocks')
    else:
        ax.text(0.5, 0.5, 'APT factor loadings not calculated.',
                horizontalalignment='center', verticalalignment='center')

def _plot_portfolio_factor_exposure(self, ax):

```

```

"""Plot weighted average factor exposure for the final APT portfolio."""
ax.set_title('Portfolio Factor Exposures (APT Model)', fontsize=11, u
↪fontweight='bold')
if ('apt' in self.factor_loadings and 'apt' in self.models and
    'optimal_weights' in self.models['apt']):
    loadings_df = self.factor_loadings['apt']
    weights = self.models['apt']['optimal_weights']

    # Calculate weighted average portfolio loadings
    portfolio_loadings = loadings_df.T @ weights
    portfolio_loadings = portfolio_loadings.sort_values()

    # Create horizontal bar plot
    colors = [f"#{PORTFOLIO_COLORS['success']}" if x > 0 else u
↪f"#{PORTFOLIO_COLORS['accent']}"]
    for x in portfolio_loadings.values]
    bars = ax.barh(portfolio_loadings.index, portfolio_loadings.values, u
↪color=colors)
    ax.set_xlabel('Portfolio Loading')
    ax.axvline(0, color='black', linewidth=0.5, linestyle='--')

    # Add value labels
    for bar in bars:
        width = bar.get_width()
        x_pos = width + 0.01 if width > 0 else width - 0.01
        ha = 'left' if width > 0 else 'right'
        ax.text(x_pos, bar.get_y() + bar.get_height()/2,
                f'{width:.3f}', ha=ha, va='center', fontsize=7)
    else:
        ax.text(0.5, 0.5, 'Run APT optimization to see exposures.',
               horizontalalignment='center', verticalalignment='center')

def _plot_scenario_risk_metrics(self, ax):
    """Plot grouped bar chart of risk metrics for scenarios."""
    ax.set_title('Scenario Risk Metrics (VaR, CVaR, MDD)', fontsize=11, u
↪fontweight='bold')

    if not self.what_if_scenarios:
        ax.text(0.5, 0.5, 'Scenarios not yet generated.',
               horizontalalignment='center', verticalalignment='center')
        return

    plot_data = []
    for scenario_name, data in self.what_if_scenarios.items():
        metrics = data['metrics']
        plot_data.append({

```

```

        'Scenario': scenario_name,
        'Metric': 'Max Drawdown',
        'Value': metrics['Max_Drawdown']
    })
plot_data.append({
    'Scenario': scenario_name,
    'Metric': 'VaR 95%',
    'Value': metrics['VaR_95']
})
plot_data.append({
    'Scenario': scenario_name,
    'Metric': 'CVaR 95%',
    'Value': metrics['CVaR_95']
})

df = pd.DataFrame(plot_data)

# Plot the risk metrics
sns.barplot(data=df, x='Metric', y='Value', hue='Scenario', ax=ax,
             palette={'Conservative': 'green', 'Moderate': 'orange', ↴
             'Aggressive': 'red'})

ax.set_ylabel('Potential Loss (%)')
ax.set_xlabel('Risk Metric')
ax.yaxis.set_major_formatter(FuncFormatter(lambda y, _: f'{y:.0%}'))
ax.legend(title='Scenario')

# Add Sharpe Ratios on a secondary axis
ax2 = ax.twinx()
sharpe_data = []
for scenario_name, data in self.what_if_scenarios.items():
    sharpe_data.append({
        'Scenario': scenario_name,
        'Metric': 'Sharpe Ratio',
        'Value': data['metrics']['Sharpe_Ratio']
    })

df_sharpe = pd.DataFrame(sharpe_data)

# Manually create stripplot for secondary axis
metrics_list = ['Max Drawdown', 'VaR 95%', 'CVaR 95%']
scenarios_list = ['Conservative', 'Moderate', 'Aggressive']
jitter = 0.2

for i, metric in enumerate(metrics_list):
    for j, scenario in enumerate(scenarios_list):
        if i == 0:
            ...

```

```

    val = df_sharpe[df_sharpe['Scenario'] == scenario]['Value'].

values[0]
    x_pos = j*jitter - (jitter * (len(scenarios_list)-1)/2)
    ax2.plot(x_pos, val, 'D', color='black',
              label=f'{scenario} Sharpe' if j==0 else None)

ax2.set_ylabel('Sharpe Ratio')
ax2.grid(False)
ax2.legend(loc='upper right', fontsize=7)

def _plot_return_distribution(self, ax):
    """Plot histogram of simulated returns with VaR/CVaR."""
    ax.set_title('Return Distribution (APT Model)', fontsize=11,
fontweight='bold')

    if 'apt' in self.models and 'optimal_weights' in self.models['apt']:
        weights = self.models['apt']['optimal_weights']
        returns = self.returns @ weights

        # Calculate metrics
        metrics = self.evaluate_portfolio(weights)
        # Convert annualized VaR/CVaR back to daily for plotting
        var_95 = metrics['VaR_95'] / np.sqrt(self.
model_params['trading_days'])
        cvar_95 = metrics['CVaR_95'] / np.sqrt(self.
model_params['trading_days'])

        # Plot histogram
        sns.histplot(returns, bins=50, kde=True, ax=ax, stat='density',
color=f"#{PORTFOLIO_COLORS['secondary']}")

        # Plot VaR/CVaR
        ax.axvline(var_95, color=f"#{PORTFOLIO_COLORS['warning']}",
linestyle='--',
                  label=f'VaR 95% ({var_95:.2%})')
        ax.axvline(cvar_95, color=f"#{PORTFOLIO_COLORS['success']}",
linestyle='-',
                  label=f'CVaR 95% ({cvar_95:.2%})')

        ax.set_xlabel('Daily Returns')
        ax.set_ylabel('Density')
        ax.xaxis.set_major_formatter(FuncFormatter(lambda x, p: f'{x:.1%}'))
        ax.legend()
    else:
        ax.text(0.5, 0.5, 'Run APT optimization to see distribution.',
horizontalalignment='center', verticalalignment='center')

```

```

def _plot_ff3_loadings_heatmap(self, ax):
    """Plot heatmap of Fama-French 3-factor loadings."""
    ax.set_title('Fama-French 3-Factor Loadings', fontsize=11,
    fontweight='bold')
    if 'ff3' in self.factor_loadings and not self.factor_loadings['ff3'].empty:
        # Get the relevant columns, drop Alpha
        ff3_loadings = self.factor_loadings['ff3'].drop(columns=['Alpha'],
        errors='ignore')
        sns.heatmap(ff3_loadings, annot=True, fmt='.2f',
                    cmap='RdBu_r', center=0, ax=ax,
                    linewidths=0.5, cbar_kws={'label': 'Factor Loading'})
        ax.set_xlabel('Fama-French 3 Factors')
        ax.set_ylabel('Stocks')
    else:
        ax.text(0.5, 0.5, 'FF3 factor loadings not calculated.',
                horizontalalignment='center', verticalalignment='center')

def _plot_capm_analysis(self, ax):
    """Plot CAPM Alpha vs. Beta (Mkt-RF) from FF3 regression."""
    ax.set_title('CAPM Analysis (from FF3 Regression)', fontsize=11,
    fontweight='bold')
    if 'ff3' in self.factor_loadings and not self.factor_loadings['ff3'].empty:
        capm_data = self.factor_loadings['ff3'][['Alpha', 'Mkt-RF']].copy()
        capm_data.rename(columns={'Mkt-RF': 'Beta'}, inplace=True)

        # Annualized Alpha vs. Beta
        ax.scatter(capm_data['Beta'], capm_data['Alpha'],
                   c=f"#{{{PORTFOLIO_COLORS['primary']}}}", s=60, alpha=0.7,
                   edgecolors='black')

        # Add labels
        for ticker, row in capm_data.iterrows():
            ax.text(row['Beta'] + 0.02, row['Alpha'], ticker, fontsize=8)

        ax.axhline(0, color='grey', linestyle='--', linewidth=1)
        ax.axvline(1, color='grey', linestyle='--', linewidth=1,
        label='Market Beta (1.0)')

        ax.set_xlabel('Market Beta (Mkt-RF)')
        ax.set_ylabel('Annualized Alpha')
        ax.yaxis.set_major_formatter(FuncFormatter(lambda y, _: f'{y:.2%}'))
        ax.legend(loc='best')
    else:

```

```

        ax.text(0.5, 0.5, 'CAPM (FF3) data not calculated.',
                 horizontalalignment='center', verticalalignment='center')

    def _plot_ff5_loadings_heatmap(self, ax):
        """Plot heatmap of Fama-French 5-factor loadings."""
        ax.set_title('Fama-French 5-Factor Loadings', fontsize=11,
                     fontweight='bold')
        if 'ff5' in self.factor_loadings and not self.factor_loadings['ff5'].empty:
            # Get the relevant columns, drop Alpha
            ff5_loadings = self.factor_loadings['ff5'].drop(columns=['Alpha'],
                     errors='ignore')
            sns.heatmap(ff5_loadings, annot=True, fmt='.2f',
                        cmap='RdBu_r', center=0, ax=ax,
                        linewidths=0.5, cbar_kws={'label': 'Factor Loading'})
            ax.set_xlabel('Fama-French 5 Factors')
            ax.set_ylabel('Stocks')
        else:
            ax.text(0.5, 0.5, 'FF5 factor loadings not calculated.',
                    horizontalalignment='center', verticalalignment='center')

    def _plot_carhart_loadings_heatmap(self, ax):
        """Plot heatmap of Carhart 4-factor loadings."""
        ax.set_title('Carhart 4-Factor Loadings', fontsize=11,
                     fontweight='bold')
        if 'carhart' in self.factor_loadings and not self.factor_loadings['carhart'].empty:
            # Get the relevant columns, drop Alpha
            carhart_loadings = self.factor_loadings['carhart'].drop(columns=['Alpha'],
                     errors='ignore')
            sns.heatmap(carhart_loadings, annot=True, fmt='.2f',
                        cmap='RdBu_r', center=0, ax=ax,
                        linewidths=0.5, cbar_kws={'label': 'Factor Loading'})
            ax.set_xlabel('Carhart 4 Factors (Mkt, SMB, HML, Mom)')
            ax.set_ylabel('Stocks')
        else:
            ax.text(0.5, 0.5, 'Carhart factor loadings not calculated.',
                    horizontalalignment='center', verticalalignment='center')

    def _plot_model_r_squared(self, ax):
        """Plot R-squared values for different factor models."""
        ax.set_title('Model Explanatory Power (R-squared)', fontsize=11,
                     fontweight='bold')

    r2_data = {}

```

```

        if 'ff3_stats' in self.factor_loadings and not self.
    ↵factor_loadings['ff3_stats'].empty:
            r2_data['FF3'] = self.factor_loadings['ff3_stats']['R2']
        if 'ff5_stats' in self.factor_loadings and not self.
    ↵factor_loadings['ff5_stats'].empty:
            r2_data['FF5'] = self.factor_loadings['ff5_stats']['R2']
        if 'carhart_stats' in self.factor_loadings and not self.
    ↵factor_loadings['carhart_stats'].empty:
            r2_data['Carhart'] = self.factor_loadings['carhart_stats']['R2']
        if 'apt_stats' in self.factor_loadings and not self.
    ↵factor_loadings['apt_stats'].empty:
            r2_data['APT'] = self.factor_loadings['apt_stats']['R2']

    if r2_data:
        df = pd.DataFrame(r2_data).dropna()
        df.plot(kind='bar', ax=ax,
                 color=[f"#{PORTFOLIO_COLORS['primary']}",
                        f"#{PORTFOLIO_COLORS['secondary']}",
                        f"#{PORTFOLIO_COLORS['accent']}",
                        f"#{PORTFOLIO_COLORS['success']}"])

        ax.set_ylabel('R-squared')
        ax.set_xlabel('Stocks')
        ax.yaxis.set_major_formatter(FuncFormatter(lambda y, _: f'{y:.0%}'))
        ax.tick_params(axis='x', rotation=45)
        ax.legend(title='Model')
    else:
        ax.text(0.5, 0.5, 'Model R-squared data not available.',
                horizontalalignment='center', verticalalignment='center')

class PortfolioExcelGenerator:
    """
    Generate comprehensive Excel workbook for academic project submission.

    EXCEL SHEETS:
    1. Executive Summary - Key metrics and recommendations
    2. Dashboard - Visual overview
    3. Solver-Ready - Optimization model for Excel Solver
    4. Data - Input data and parameters
    5. Sensitivity - What-If analysis results
    6. Factor Loadings - Factor model results
    7. Assumptions - Model assumptions and limitations
    """
    def __init__(self, optimizer):
        self.optimizer = optimizer
        self.wb = Workbook()

```

```

# Define professional styles
self._setup_styles()

def _setup_styles(self):
    """Setup Excel styles for professional formatting."""

    self.header_style = NamedStyle(name="header_style")
    self.header_style.font = Font(bold=True, size=12, color="FFFFFF")
    self.header_style.fill = PatternFill(
        start_color=PORTFOLIO_COLORS['table_header'],
        end_color=PORTFOLIO_COLORS['table_header'],
        fill_type="solid"
    )
    self.header_style.alignment = Alignment(horizontal="center")

    self.title_style = NamedStyle(name="title_style")
    self.title_style.font = Font(bold=True, size=14, ↴
                                color=PORTFOLIO_COLORS['primary'])

    self.pct_style = NamedStyle(name="pct_style", number_format='0.00%')
    self.pct_style_bold = NamedStyle(name="pct_style_bold", ↴
                                    number_format='0.00%')
    self.pct_style_bold.font = Font(bold=True)

    self.float_style = NamedStyle(name="float_style", number_format='0.000')
    self.float_style_bold = NamedStyle(name="float_style_bold", ↴
                                       number_format='0.000')
    self.float_style_bold.font = Font(bold=True)

    self.label_style = NamedStyle(name="label_style")
    self.label_style.font = Font(bold=True)

    # Add styles to workbook
    try:
        for style in [self.header_style, self.title_style, self.pct_style,
                      self.pct_style_bold, self.float_style, self.
                      ↴float_style_bold,
                      self.label_style]:
            if style.name not in self.wb.named_styles:
                self.wb.add_named_style(style)
    except Exception as e:
        print(f"Could not add style: {e}")

def create_excel_file(self, filename='Final_Project.xlsx'):
    """
    Main method to create complete Excel workbook.

```

```

DELIVERABLE:
Excel file ready for submission with all required elements.
"""

print("Creating Excel workbook...")

# Remove default sheet
if 'Sheet' in self.wb.sheetnames:
    self.wb.remove(self.wb['Sheet'])

# Create all sheets
self._create_executive_summary()
self._create_data_sheet() # Data sheet must be created before Solver sheet
self._create_sensitivity_sheet()
self._create_optimization_sheet() # Solver sheet depends on Data sheet
self._create_dashboard_sheet() # Dashboard depends on Solver sheet
self._create_factor_sheet()
self._create_assumptions_sheet()

# Set active sheet to Executive Summary
self.wb.active = self.wb['Executive Summary']

try:
    self.wb.save(filename)
    print(f"  Excel file saved: {filename}")
    return filename
except Exception as e:
    print(f"  Failed to save Excel file: {e}")
    raise

def _create_executive_summary(self):
    """
Create Executive Summary sheet.

BUSINESS PURPOSE:
One-page summary.
"""

ws = self.wb.create_sheet("Executive Summary")

# Title
ws['A1'] = 'PORTFOLIO OPTIMIZATION ANALYSIS'
ws['A1'].style = self.title_style
ws.merge_cells('A1:E1')
ws['A2'] = 'Technology Sector Investment Strategy'
ws.merge_cells('A2:E2')

```

```

# Project Context
ws['A4'] = 'BUSINESS PROBLEM'
ws['A4'].style = self.label_style
ws.merge_cells('A4:E4')
ws['A5'] = 'Optimize $10M tech portfolio across 7 stocks to maximize risk-adjusted returns'
ws.merge_cells('A5:E5')
ws.row_dimensions[5].height = 30
ws['A5'].alignment = Alignment(wrap_text=True)

# Key Findings
ws['A7'] = 'KEY FINDINGS'
ws['A7'].style = self.label_style
ws.merge_cells('A7:E7')

if 'optimal_weights' in self.optimizer.models['apt']:
    weights = self.optimizer.models['apt']['optimal_weights']
    metrics = self.optimizer.evaluate_portfolio(weights)

    findings = [
        ('Recommended Strategy', 'APT-based optimization (Moderate)'),
        ('Expected Annual Return', f'{metrics["Expected_Return"]:.1%}'),
        ('Portfolio Volatility (Risk)', f'{metrics["Volatility"]:.1%}'),
        ('Sharpe Ratio', f'{metrics["Sharpe_Ratio"]:.2f}'),
        ('Diversification', f'{metrics["Active_Positions"]} stocks (>5% each)'),
        ('Maximum Drawdown', f'{metrics["Max_Drawdown"]:.1%}')
    ]

    for i, (label, value) in enumerate(findings, 8):
        ws[f'A{i}'] = label
        ws[f'A{i}'].style = self.label_style
        ws[f'C{i}'] = value

# Recommendations
row = 15
ws[f'A{row}'] = 'RECOMMENDATIONS'
ws[f'A{row}'].style = self.label_style
ws.merge_cells(f'A{row}:E{row}')

recommendations = [
    '1. Implement APT-based portfolio for better factor risk management',
    '2. Maintain diversification: minimum 5 active positions',
    '3. Review quarterly due to tech sector volatility',
    '4. Monitor macro factors (inflation, credit spreads, term structure)'
]

```

```

'5. Consider rebalancing when any position exceeds 30%'
]

for i, rec in enumerate(recommendations, row + 1):
    ws[f'A{i}'] = rec
    ws.merge_cells(f'A{i}:E{i}')
    ws.row_dimensions[i].height = 20

# Formatting
ws.column_dimensions['A'].width = 30
ws.column_dimensions['C'].width = 20

print("  Executive Summary created")

def _create_dashboard_sheet(self):
    """Create Dashboard sheet with KPIs and charts."""
    ws = self.wb.create_sheet("Dashboard")
    n = len(self.optimizer.tickers)

    ws['A1'] = 'Portfolio Optimization Dashboard'
    ws['A1'].style = self.title_style
    ws.merge_cells('A1:F1')

    # Key Performance Indicators
    ws['A3'] = 'Key Performance Indicators (APT Model)'
    ws['A3'].style = self.label_style
    ws.merge_cells('A3:C3')

    metrics = [
        ('Expected Return', "'Solver-Ready'!H13", self.pct_style_bold),
        ('Portfolio Volatility', "'Solver-Ready'!H8", self.pct_style_bold),
        ('Sharpe Ratio', "'Solver-Ready'!H15", self.float_style_bold),
        (
            'Active Positions (>5%)',
            f"=COUNTIF('Solver-Ready'!B5:{get_column_letter(n+1)}5, >0.05\")",
            '0'
        )
    ]

    for i, (label, formula, style) in enumerate(metrics, 4):
        ws[f'A{i}'] = label
        ws[f'B{i}'] = formula
        if hasattr(style, 'number_format'):
            ws[f'B{i}'].number_format = style.number_format
        else:
            ws[f'B{i}'].number_format = style

```

```

ws[f'B{i}'].font = Font(bold=True) # Make values bold

# Optimal Weights Chart
if 'Solver-Ready' in self.wb.sheetnames:
    ws['D3'] = 'Optimal Weights (APT Model)'
    ws['D3'].style = self.label_style

chart = BarChart()
chart.title = "Optimal Portfolio Weights"
chart.style = 13
chart.y_axis.title = 'Weight'
chart.x_axis.title = 'Stock'

data_ref = Reference(self.wb['Solver-Ready'],
                     min_col=2, min_row=5, max_col=n+1, max_row=5)
cat_ref = Reference(self.wb['Solver-Ready'],
                     min_col=2, min_row=4, max_col=n+1, max_row=4)

series = Series(data_ref, title="Optimal Weights")
chart.series.append(series)
chart.set_categories(cat_ref)
chart.legend = None

ws.add_chart(chart, "D5")
chart.width = 15
chart.height = 10

# Sensitivity Chart
if 'Sensitivity' in self.wb.sheetnames and not self.optimizer.
    sensitivity_results.empty:
    ws['A18'] = 'Sensitivity Analysis'
    ws['A18'].style = self.label_style

    sens_chart = ScatterChart()
    sens_chart.title = "Efficient Frontier (Risk vs. Target Return)"
    sens_chart.style = 13
    sens_chart.x_axis.title = 'Target Return'
    sens_chart.y_axis.title = 'Portfolio Risk (Volatility)'

    xvalues = Reference(self.wb['Sensitivity'],
                         min_col=1, min_row=3,
                         max_row=len(self.optimizer.
    sensitivity_results)+2)
    yvalues = Reference(self.wb['Sensitivity'],
                         min_col=3, min_row=3,
                         max_row=len(self.optimizer.
    sensitivity_results)+2)

```

```

        series = Series(yvalues, xvalues, title="Risk")
        sens_chart.series.append(series)
        sens_chart.legend = None

        ws.add_chart(sens_chart, "A20")
        sens_chart.width = 15
        sens_chart.height = 10

        ws.column_dimensions['A'].width = 25
        ws.column_dimensions['B'].width = 15
        ws.column_dimensions['D'].width = 15

        print(" Dashboard created")

    def _create_optimization_sheet(self):
        """
        Create Solver-Ready optimization sheet.

        EXCEL SOLVER SETUP:
        1. Set Objective: H8 (Minimize portfolio volatility)
        2. By Changing: B5:H5 (Portfolio weights, or 'PortfolioWeights' named
        ↪range)
        3. Constraints:
            - E11 = G11 (Sum of weights = 1)
            - E12 >= G12 (Return >= 15%)
            - E13 <= G13 (Max weight <= 30%)
            - E14 >= G14 (Min weight >= 0%)
        """
        ws = self.wb.create_sheet("Solver-Ready")
        n = len(self.optimizer.tickers)

        ws['A1'] = 'Portfolio Optimization Model (Solver-Ready)'
        ws['A1'].style = self.title_style

        # Decision Variables
        ws['A3'] = '1. Decision Variables (Weights)'
        ws['A3'].style = self.label_style

        ws.cell(row=4, column=1, value='Stock').style = self.header_style
        ws.cell(row=5, column=1, value='Weights').style = self.label_style

        opt_weights = self.optimizer.models['apt'].get('optimal_weights')
        if opt_weights is None:
            opt_weights = [1/n] * n

        for i, ticker in enumerate(self.optimizer.tickers, 2):

```

```

ws.cell(row=4, column=i, value=ticker).style = self.header_style
ws.cell(row=5, column=i, value=opt_weights[i-2]).style = self.
↪pct_style

weights_range_name = 'PortfolioWeights'
weights_range_ref = f"'Solver-Ready'!$B$5:$${get_column_letter(n+1)}$5"
dn = DefinedName(name=weights_range_name, attr_text=weights_range_ref)
self.wb.defined_names[weights_range_name] = dn

# Objective Function
ws['A7'] = '2. Objective Function'
ws['A7'].style = self.label_style
ws['A8'] = 'Portfolio Volatility'
ws['A8'].style = self.label_style
ws['G8'] = 'Objective (Minimize):'
ws['H8'] = f"=SQRT(H14)"
ws['H8'].style = self.pct_style_bold

# Constraints
ws['A10'] = '3. Constraints'
ws['A10'].style = self.label_style
ws['E10'] = 'LHS'
ws['F10'] = 'Sign'
ws['G10'] = 'RHS'

weights_range = weights_range_name
returns_range = "'Data'!B4:" + get_column_letter(n+1) + "4"

constraints = [
    ('Sum of Weights', f'=SUM({weights_range})', '=', 1),
    ('Portfolio Return', ↪
     f'=SUMPRODUCT({weights_range},{returns_range})', '>=', 0.15),
    (f'Weights <= 30%', f'=MAX({weights_range})', '<=', "'Data'!B10"), ↪
    # Link to param
    ('Weights >= 0', f'=MIN({weights_range})', '>=', 0)
]

for i, (label, lhs, sign, rhs) in enumerate(constraints, 11):
    ws[f'D{i}'] = label
    ws[f'E{i}'] = lhs
    ws[f'F{i}'] = sign
    ws[f'G{i}'] = rhs
    if isinstance(rhs, float) and rhs < 1:
        ws[f'G{i}'].style = self.pct_style
    if "Data" in str(rhs):
        ws[f'G{i}'].style = self.pct_style

```

```

# Calculations
ws['F12'] = 'Calculations'
ws['F13'] = 'Portfolio Return'
ws['F14'] = 'Portfolio Variance'
ws['F15'] = 'Sharpe Ratio'

ws['H13'] = f"=SUMPRODUCT({weights_range},{returns_range})"
ws['H13'].style = self.pct_style_bold

ws['H14'] = f"=SUMPRODUCT(MMULT({weights_range_name},"
ws['H14'] += CovarianceMatrix, {weights_range_name})"
ws['H14'].style = self.float_style

# Link to risk-free rate on Data sheet
ws['H15'] = f"=(H13 - 'Data'!B7) / H8"
ws['H15'].style = self.float_style_bold

# Add data validation for weights
dv = DataValidation(type="decimal", operator="between",
                     formula1=0, formula2="='Data'!B10") # Link to param
dv.error = 'Weight must be between 0% and 30%'
dv.errorTitle = 'Invalid Weight'
ws.add_data_validation(dv)
dv.add(f'B5:{get_column_letter(n+1)}5')

# Column widths
ws.column_dimensions['A'].width = 30
ws.column_dimensions['D'].width = 30
ws.column_dimensions['E'].width = 20
ws.column_dimensions['H'].width = 20

print(" Solver-Ready sheet created")

def _create_data_sheet(self):
    """Create Data sheet with input parameters."""
    ws = self.wb.create_sheet("Data")
    n = len(self.optimizer.tickers)

    ws['A1'] = 'Model Input Data'
    ws['A1'].style = self.title_style

    # Expected Returns
    ws['A3'] = 'Expected Annual Returns'
    ws['A3'].style = self.label_style

    for i, ticker in enumerate(self.optimizer.tickers, 2):
        ws.cell(row=3, column=i, value=ticker).style = self.header_style

```

```

        ws.cell(row=4, column=i,
                  value=self.optimizer.expected_returns[ticker]).style = self.
        ↪pct_style

    # Model Parameters
    ws['A6'] = 'Model Parameters'
    ws['A6'].style = self.label_style

    params = [
        ('Risk-Free Rate', self.optimizer.model_params['risk_free_rate']),
        ('Transaction Cost', self.optimizer.
        ↪model_params['transaction_cost']),
        ('Min Position Size', self.optimizer.
        ↪model_params['min_investment']),
        ('Max Position Size', self.optimizer.
        ↪model_params['max_investment']),
        ('Target Return Cap', self.optimizer.
        ↪model_params['target_return_cap']),
        ('Min Active Stocks', self.optimizer.
        ↪model_params['min_stocks_active'])
    ]

    for i, (label, value) in enumerate(params, 7):
        ws[f'A{i}'] = label
        ws[f'B{i}'] = value
        if isinstance(value, float) and value < 1:
            ws[f'B{i}'].style = self.pct_style
        elif isinstance(value, int):
            ws[f'B{i}'].number_format = '0'

    # Covariance Matrix
    ws['A14'] = 'Annualized Covariance Matrix'
    ws['A14'].style = self.label_style

    # Headers
    for i, ticker in enumerate(self.optimizer.tickers, 3):
        ws.cell(row=14, column=i, value=ticker).style = self.header_style
        ws.cell(row=i+11, column=2, value=ticker).style = self.header_style
    ↪# Adjusted row index

    # Data
    cov_data = self.optimizer.cov_matrix.values
    for r_idx, row in enumerate(cov_data, 15):
        for c_idx, value in enumerate(row, 3):
            ws.cell(row=r_idx, column=c_idx, value=value).number_format = ↪
        ↪'0.00000'

```

```

# --- Create Named Range for Covariance Matrix ---
cov_range_name = 'CovarianceMatrix'
cov_range_ref = f"'Data'!$C$15:$${get_column_letter(n+2)}${15 + n - 1}"
# Create a DefinedName object
dn_cov = DefinedName(name=cov_range_name, attr_text=cov_range_ref)
# Add it to the workbook's defined_names dictionary
self.wb.defined_names[cov_range_name] = dn_cov

# Column widths
ws.column_dimensions['A'].width = 30
for i in range(2, n + 3):
    ws.column_dimensions[get_column_letter(i)].width = 15

print(" Data sheet created")

def _create_sensitivity_sheet(self):
    """Create Sensitivity Analysis sheet for What-If scenarios."""
    ws = self.wb.create_sheet("Sensitivity")

    ws['A1'] = 'Sensitivity Analysis Results'
    ws['A1'].style = self.title_style

    if self.optimizer.sensitivity_results.empty:
        ws['A3'] = "Sensitivity analysis results not available."
        return

    # Headers
    headers = ['Target Return', 'Actual Return', 'Risk (Volatility)', ↴
               'Active Stocks']
    for col, header in enumerate(headers, 1):
        ws.cell(row=2, column=col, value=header).style = self.header_style

    # Data
    df = self.optimizer.sensitivity_results
    for r_idx, row in enumerate(df.itertuples(), 3):
        ws.cell(row=r_idx, column=1, value=row.Target).style = self.↪
            pct_style
        ws.cell(row=r_idx, column=2, value=row.Actual_Return).style = self.↪
            pct_style
        ws.cell(row=r_idx, column=3, value=row.Risk).style = self.pct_style
        ws.cell(row=r_idx, column=4, value=row.Active_Stocks)

    # Add What-If scenario names
    if self.optimizer.what_if_scenarios:
        ws['F2'] = 'What-If Scenarios'
        ws['F2'].style = self.label_style

```

```

row = 3
for name, data in self.optimizer.what_if_scenarios.items():
    ws[f'F{row}'] = name
    ws[f'G{row}'] = data['params']['target_return']
    ws[f'G{row}'].style = self.pct_style
    ws[f'H{row}'] = data['metrics']['Volatility']
    ws[f'H{row}'].style = self.pct_style
    row += 1

# Column widths
for i, col_width in enumerate([20, 20, 20, 15], 1):
    ws.column_dimensions[get_column_letter(i)].width = col_width

print(" Sensitivity sheet created")

def _create_factor_sheet(self):
    """Create Factor Loadings sheet."""
    ws = self.wb.create_sheet("Factor Loadings")

    ws['A1'] = 'Factor Model Loadings (Betas)'
    ws['A1'].style = self.title_style

    current_row = 3

    # Helper function to add DataFrame to sheet
    def add_df_to_sheet(df, start_row):
        # Add index name
        headers = [df.index.name if df.index.name else "Ticker"] + list(df.
    ↪columns)
        for c_idx, header in enumerate(headers, 1):
            ws.cell(row=start_row, column=c_idx, value=header).style = self.
    ↪header_style

        # Add data
        for r_idx, (index_val, row_data) in enumerate(df.iterrows(), ↪
    ↪start_row + 1):
            ws.cell(row=r_idx, column=1, value=index_val) # Write index
            for c_idx, value in enumerate(row_data, 2): # Write data
                cell = ws.cell(row=r_idx, column=c_idx, value=value)
                if isinstance(value, (int, float)):
                    cell.number_format = '0.000'

    return start_row + len(df) + 2 # Return next available row

# APT Loadings

```

```

        if 'apt' in self.optimizer.factor_loadings and not self.optimizer.
        ↪factor_loadings['apt'].empty:
            ws[f'A{current_row}'] = 'APT Macro-Factor Loadings'
            ws[f'A{current_row}'].style = self.label_style
            current_row += 1
            df_apt = self.optimizer.factor_loadings['apt']
            current_row = add_df_to_sheet(df_apt, current_row)

        # FF3 Loadings
        if 'ff3' in self.optimizer.factor_loadings and not self.optimizer.
        ↪factor_loadings['ff3'].empty:
            ws[f'A{current_row}'] = 'Fama-French 3-Factor Loadings'
            ws[f'A{current_row}'].style = self.label_style
            current_row += 1
            df_ff3 = self.optimizer.factor_loadings['ff3']
            current_row = add_df_to_sheet(df_ff3, current_row)

        # FF5 Loadings
        if 'ff5' in self.optimizer.factor_loadings and not self.optimizer.
        ↪factor_loadings['ff5'].empty:
            ws[f'A{current_row}'] = 'Fama-French 5-Factor Loadings'
            ws[f'A{current_row}'].style = self.label_style
            current_row += 1
            df_ff5 = self.optimizer.factor_loadings['ff5']
            current_row = add_df_to_sheet(df_ff5, current_row)

        # Carhart 4-Factor Loadings
        if 'carhart' in self.optimizer.factor_loadings and not self.optimizer.
        ↪factor_loadings['carhart'].empty:
            ws[f'A{current_row}'] = 'Carhart 4-Factor Loadings'
            ws[f'A{current_row}'].style = self.label_style
            current_row += 1
            df_carhart = self.optimizer.factor_loadings['carhart']
            current_row = add_df_to_sheet(df_carhart, current_row)

        # Column widths
        ws.column_dimensions['A'].width = 25
        for i in range(2, 10):
            ws.column_dimensions[get_column_letter(i)].width = 15

        print(" Factor Loadings sheet created")

    def _create_assumptions_sheet(self):
        """
        Create Assumptions & Limitations sheet.
        """

    ACADEMIC REQUIREMENT:
```

```

Analysis must recognize assumptions and limitations.
"""

ws = self.wb.create_sheet("Assumptions")

ws['A1'] = 'Model Assumptions & Limitations'
ws['A1'].style = self.title_style
ws.merge_cells('A1:D1')

# Key Assumptions
ws['A3'] = 'KEY ASSUMPTIONS'
ws['A3'].style = self.label_style
ws.merge_cells('A3:D3')

assumptions = [
    '1. Historical Performance: Past returns are indicative of future',
    '    → Limitation: Market regimes change; past may not predict',
    'future',
    '',
    '2. Normal Distribution: Returns follow multivariate normal',
    'distribution',
    '    → Limitation: Real returns have fat tails (extreme events more',
    'common)',
    '',
    '3. Constant Correlations: Stock correlations remain stable over',
    'time',
    '    → Limitation: Correlations increase during market stress',
    '',
    '4. No Market Impact: Portfolio rebalancing does not affect prices',
    '    → Limitation: Large trades can move markets',
    '',
    '5. Transaction Costs: Fixed at 0.1% regardless of size',
    '    → Limitation: Actual costs vary by trade size and liquidity',
    '',
    '6. Annual Rebalancing: Portfolio reviewed annually',
    '    → Limitation: Tech sector volatility may require quarterly',
    'reviews'
]

for i, assumption in enumerate(assumptions, 4):
    ws[f'A{i}'] = assumption
    ws.merge_cells(f'A{i}:D{i}')
    ws.row_dimensions[i].height = 20
    ws[f'A{i}'].alignment = Alignment(wrap_text=True)

# Model Limitations

```

```

row = 4 + len(assumptions) + 2
ws[f'A{row}'] = 'MODEL LIMITATIONS'
ws[f'A{row}'].style = self.label_style
ws.merge_cells(f'A{row}:D{row}')

limitations = [
    '1. Single Period: Optimizes for single period, not dynamic rebalancing',
    '    → Real portfolios need multi-period optimization',
    '',
    '2. No Taxes: Does not account for capital gains taxes',
    '    → Tax considerations can significantly impact net returns',
    '',
    '3. No Market Timing: Assumes buy-and-hold strategy',
    '    → Tactical allocation could improve performance',
    '',
    '4. Tech Sector Only: Portfolio limited to 7 tech stocks',
    '    → Broader diversification across sectors recommended'
]

row += 1
for i, limitation in enumerate(limitations, row):
    ws[f'A{i}'] = limitation
    ws.merge_cells(f'A{i}:D{i}')
    ws.row_dimensions[i].height = 20
    ws[f'A{i}'].alignment = Alignment(wrap_text=True)

# Data Sources
row = row + len(limitations) + 2
ws[f'A{row}'] = 'DATA SOURCES & REFERENCES'
ws[f'A{row}'].style = self.label_style
ws.merge_cells(f'A{row}:D{row}')

references = [
    'Academic References:',
    '• Markowitz, H. (1952). "Portfolio Selection." Journal of Finance, 7(1), 77-91.',
    '• Fama, E. F., & French, K. R. (1993). "Common risk factors in returns on stocks and bonds."',
    '    Journal of Financial Economics, 33(1), 3-56.',
    '• Ross, S. A. (1976). "The arbitrage theory of capital asset pricing." Journal of Economic Theory, 13(3), 341-360.',
    '',
    'Data Sources (for real implementation):',
    '• Yahoo Finance API for stock prices',
    '• Kenneth French Data Library for factor data',
    '• Federal Reserve Economic Data (FRED) for macro factors'
]

```

```

]

    row += 1
    for i, ref in enumerate(references, row):
        ws[f'A{i}'] = ref
        ws.merge_cells(f'A{i}:D{i}')
        ws.row_dimensions[i].height = 15
        ws[f'A{i}'].alignment = Alignment(wrap_text=True)

    ws.column_dimensions['A'].width = 100

    print(" Assumptions sheet created")

if __name__ == "__main__":
    print("*"*80)
    print("OPRE 607 - BUSINESS ANALYTICS FINAL PROJECT")
    print("Portfolio Optimization for Technology Sector Investments")
    print("*"*80)
    print()

    # Define stocks list
    tickers = ['AAPL', 'MSFT', 'GOOGL', 'AMZN', 'NVDA', 'META', 'TSLA']

    end_date = datetime.now().strftime('%Y-%m-%d')
    print(f"Analyzing portfolio of {len(tickers)} tech stocks: {''.join(tickers)}")
    print(f"Data range: 2020-01-01 to {end_date}")
    print()

    # Initialize optimizer
    optimizer = EnhancedPortfolioOptimizer(tickers, start_date='2015-01-01', end_date=end_date)

    # Step 1: Data preparation
    print("\n" + "*"*80)
    print("STEP 1: FETCHING MARKET DATA")
    print("-" * 80)
    optimizer.fetch_all_data()

    print("\n--- Stock Correlation Matrix ---")
    print(optimizer.corr_matrix.to_string(float_format=".2f"))

    print()
    optimizer.save_data_to_excel("Tech_Portfolio_Data.xlsx")
    print("Input data successfully saved\n")

    # Step 2: Monte Carlo simulation

```

```

print("\n" + "="*80)
print("STEP 2: MONTE CARLO SIMULATION")
print("-" * 80)
optimizer.run_monte_carlo_simulation(n_simulations=100000)

print("\n--- Monte Carlo Optimal Weights (Max Sharpe) ---")
mc_weights = optimizer.models['monte_carlo']['optimal_weights']
weights_series_mc = pd.Series(mc_weights, index=optimizer.tickers,□
name="MC_Weights")
print(weights_series_mc.to_string(float_format=".4f"))
print()

# Step 3: Sensitivity analysis
print("\n" + "="*80)
print("STEP 3: SENSITIVITY ANALYSIS (WHAT-IF SCENARIOS)")
print("-" * 80)
optimizer.perform_sensitivity_analysis()
print()

# Step 4: What-If scenarios
print("\n" + "="*80)
print("STEP 4: CREATING WHAT-IF SCENARIOS")
print("-" * 80)
optimizer.create_what_if_scenarios()

print("\n--- 'Moderate' Scenario Weights (APT Model) ---")
mod_weights = optimizer.what_if_scenarios['Moderate']['weights']
weights_series_mod = pd.Series(mod_weights, index=optimizer.tickers,□
name="Moderate_Weights")
print(weights_series_mod.to_string(float_format=".4f"))
print()

# Step 5: Model comparison
print("\n" + "="*80)
print("STEP 5: COMPARING OPTIMIZATION MODELS")
print("-" * 80)
comparison = optimizer.compare_all_models_enhanced()
print()

# --- Step 6: Create Master Dashboard ---
print("\n" + "="*80)
print("STEP 6: GENERATING MASTER VISUAL DASHBOARD")
print("-" * 80)
master_dashboard_file = optimizer.
create_master_dashboard('Tech_Portfolio_Dashboard.png')
print()
# --- END NEW STEP ---

```

```

# --- Step 7: Create Excel file ---
print("\n" + "="*80)
print("STEP 7: GENERATING EXCEL FILE")
print("-" * 80)
excel_gen = PortfolioExcelGenerator(optimizer)
excel_file = excel_gen.create_excel_file('Tech_Portfolio_Report.xlsx')
print()

print("=*80)
print("ANALYSES COMPLETE!")
print("=*80)
print()
print(f" 1. Excel File: {excel_file}")
print(f"    - Executive Summary sheet")
print(f"    - Solver-Ready optimization model")
print(f"    - What-If Analysis scenarios")
print(f"    - Comprehensive data tables")
print(f"    - Assumptions & Limitations")
print(f"    - FF3, FF5, and Carhart loadings added to 'Factor Loadings' ↴tab")
print()
print(f" 2. Dashboard: {master_dashboard_file}")
print(f"    - Efficient Frontier, Correlation, Weights, Performance")
print(f"    - Risk Metrics, Sensitivity, Return Distribution")
print(f"    - CAPM, APT, FF3, FF5, Carhart Loadings")
print(f"    - R-Squared Analysis & Portfolio Factor Exposure")
print()

```

=====
OPRE 607 - BUSINESS ANALYTICS FINAL PROJECT
Portfolio Optimization for Technology Sector Investments
=====

Analyzing portfolio of 7 tech stocks: AAPL, MSFT, GOOGL, AMZN, NVDA, META, TSLA
Data range: 2020-01-01 to 2025-11-10
=====

STEP 1: FETCHING MARKET DATA

Fetching real market data...
Downloaded real stock prices from Yahoo Finance...
Downloaded 2730 days of real price data for 7 stocks
Date range: 2015-01-02 to 2025-11-07
=====

Actual Annual Expected Returns:
=====

AAPL: 26.40%

```
MSFT: 26.92%
GOOGL: 25.95%
AMZN: 30.95%
NVDA: 66.95%
META: 26.34%
TSLA: 47.94%
Validating data quality...
NVDA: 2 days with >20% daily moves
META: 4 days with >20% daily moves
TSLA: 3 days with >20% daily moves
    Capping AMZN return at 30.0% (was 30.9%)
    Capping NVDA return at 30.0% (was 67.0%)
    Capping TSLA return at 30.0% (was 47.9%)
Data validation complete
Fetching real Fama-French factors...
Downloaded real Fama-French factors
Fetching real macro factors for APT...
Downloaded real macro factors (2729 observations)
Calculating factor loadings...
    Extracted 3 principal components
    Explained variance: [0.604 0.106 0.076]
Factor loadings calculated!
Real data preparation complete!
```

```
--- Stock Correlation Matrix ---
Ticker AAPL AMZN GOOGL META MSFT NVDA TSLA
Ticker
AAPL 1.00 0.56 0.59 0.52 0.67 0.53 0.43
AMZN 0.56 1.00 0.63 0.60 0.65 0.51 0.40
GOOGL 0.59 0.63 1.00 0.61 0.69 0.52 0.38
META 0.52 0.60 0.61 1.00 0.59 0.49 0.34
MSFT 0.67 0.65 0.69 0.59 1.00 0.61 0.41
NVDA 0.53 0.51 0.52 0.49 0.61 1.00 0.41
TSLA 0.43 0.40 0.38 0.34 0.41 0.41 1.00
```

```
Saving portfolio data to Excel: Tech_Portfolio_Data.xlsx
Data successfully saved to 'Tech_Portfolio_Data.xlsx'
Input data successfully saved
```

STEP 2: MONTE CARLO SIMULATION

```
Running Monte Carlo simulation (100,000 portfolios)...
    Simulation complete!
    Best Sharpe Ratio: 0.930
    Return: 27.38%
    Risk: 25.14%
```

Risk Metrics (95% confidence):

VaR: \$-2,724,600

CVaR: \$-2,705,904

--- Monte Carlo Optimal Weights (Max Sharpe) ---

AAPL 0.2596

MSFT 0.2131

GOOGL 0.1195

AMZN 0.0245

NVDA 0.3601

META 0.0194

TSLA 0.0039

=====

STEP 3: SENSITIVITY ANALYSIS (WHAT-IF SCENARIOS)

=====

Performing sensitivity analysis (What-If scenarios)...

Running APT optimization (target: 8.0%)...

APT optimization successful

Expected return: 27.03%

Volatility: 25.02%

Running APT optimization (target: 9.9%)...

APT optimization successful

Expected return: 27.03%

Volatility: 25.02%

Running APT optimization (target: 11.8%)...

APT optimization successful

Expected return: 27.03%

Volatility: 25.02%

Running APT optimization (target: 13.7%)...

APT optimization successful

Expected return: 27.03%

Volatility: 25.02%

Running APT optimization (target: 15.6%)...

APT optimization successful

Expected return: 27.03%

Volatility: 25.02%

Running APT optimization (target: 17.4%)...

APT optimization successful

Expected return: 27.03%

Volatility: 25.02%

Running APT optimization (target: 19.3%)...

APT optimization successful

Expected return: 27.03%

Volatility: 25.02%

Running APT optimization (target: 21.2%)...

```

APT optimization successful
Expected return: 27.03%
Volatility: 25.02%
Running APT optimization (target: 23.1%)...
APT optimization successful
Expected return: 27.03%
Volatility: 25.02%
Running APT optimization (target: 25.0%)...
APT optimization successful
Expected return: 27.03%
Volatility: 25.02%
Analyzed 10 scenarios

```

Sensitivity Results:

	Target	Actual_Return	Risk	Sharpe	Active_Stocks
0	0.0800	0.2703	0.2502	0.9204	5
1	0.0989	0.2703	0.2502	0.9204	5
2	0.1178	0.2703	0.2502	0.9204	5
3	0.1367	0.2703	0.2502	0.9204	5
4	0.1556	0.2703	0.2502	0.9204	5
5	0.1744	0.2703	0.2502	0.9204	5
6	0.1933	0.2703	0.2502	0.9204	5
7	0.2122	0.2703	0.2502	0.9204	5
8	0.2311	0.2703	0.2502	0.9204	5
9	0.2500	0.2703	0.2502	0.9204	5

STEP 4: CREATING WHAT-IF SCENARIOS

```

Creating What-If scenarios...
Running APT optimization (target: 10.0%)...
APT optimization successful
Expected return: 27.03%
Volatility: 25.02%
Conservative: 27.0% return, 25.0% risk
Running APT optimization (target: 15.0%)...
APT optimization successful
Expected return: 27.03%
Volatility: 25.02%
Moderate: 27.0% return, 25.0% risk
Running APT optimization (target: 20.0%)...
APT optimization successful
Expected return: 27.03%
Volatility: 25.02%
Aggressive: 27.0% return, 25.0% risk

```

--- 'Moderate' Scenario Weights (APT Model) ---

AAPL	0.2559
MSFT	0.1421
GOOGL	0.2340
AMZN	0.0760
NVDA	0.2678
META	0.0100
TSLA	0.0141

STEP 5: COMPARING OPTIMIZATION MODELS

Comparing all models...
Running Markowitz optimization...
Markowitz optimization successful
Expected return: 26.88%
Volatility: 25.31%
Running APT optimization (target: 15.0%)...
APT optimization successful
Expected return: 27.03%
Volatility: 25.02%

Model Comparison Results:

CVaR_95	Active_Positions	Expected_Return	Volatility	Sharpe_Ratio	Max_Drawdown	VaR_95
Markowitz	-0.5775	0.2688	0.2479	0.9226	-0.3746	-0.3890
APT	-0.5856	4.0000	0.2703	0.2502	0.9204	-0.4011
Monte_Carlo	-0.5855	5.0000	0.2738	0.2514	0.9301	-0.3855
		4.0000				-0.3945

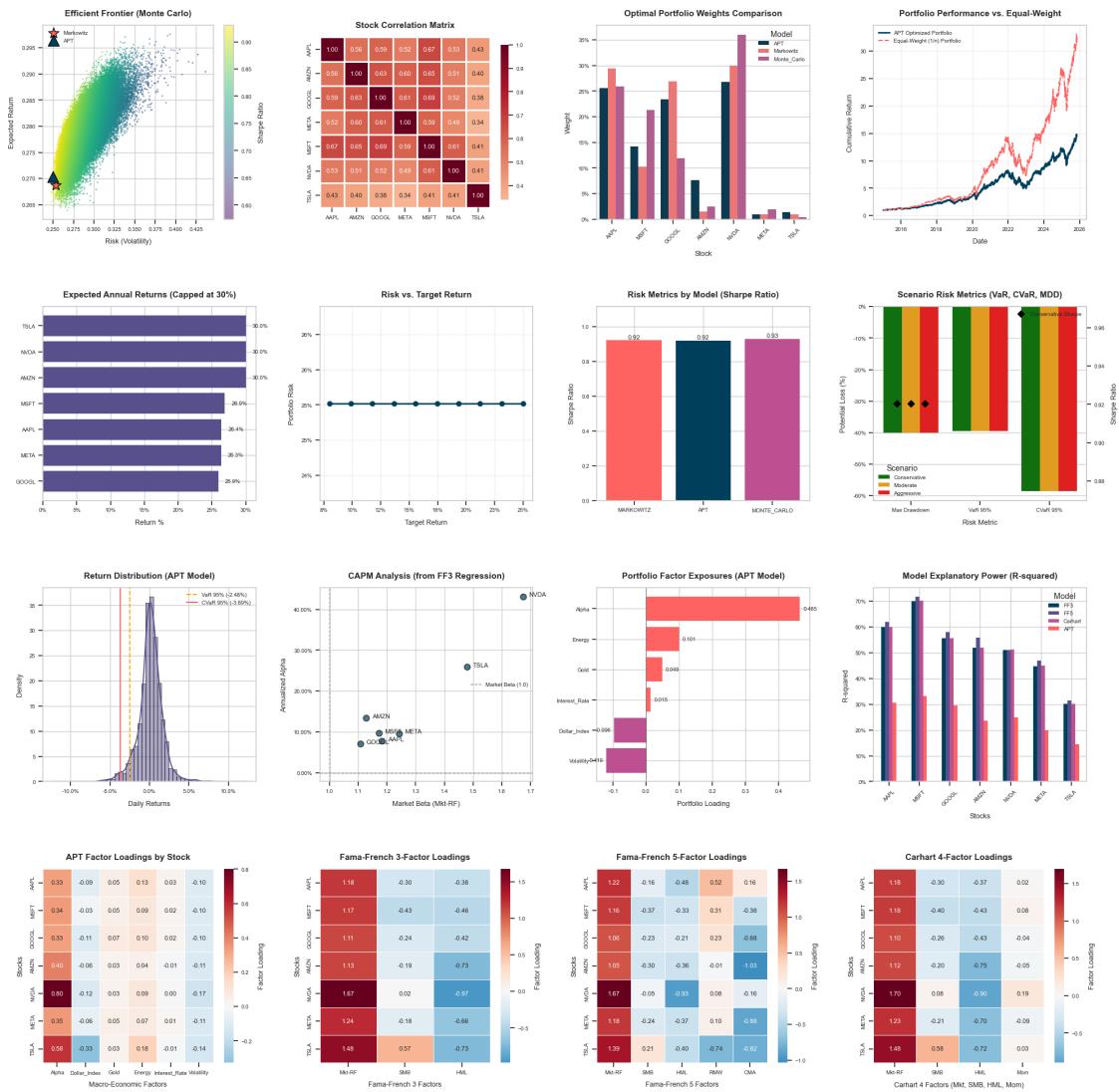
VALIDATION CHECKS

Markowitz: Return is reasonable (26.9%)
APT: Return is reasonable (27.0%)
Monte_Carlo: Return is reasonable (27.4%)

STEP 6: GENERATING MASTER VISUAL DASHBOARD

Creating master visualization dashboard...
Displaying dashboard...

**Master Portfolio Optimization Dashboard - OPRE 607 Final Project
Comprehensive Analysis**



=====
STEP 7: GENERATING EXCEL FILE
=====

Creating Excel workbook...

Executive Summary created

Data sheet created

Sensitivity sheet created

Solver-Ready sheet created

Dashboard created

Factor Loadings sheet created
Assumptions sheet created
Excel file saved: Tech_Portfolio_Report.xlsx

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ANALYSES COMPLETE!

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1. Excel File: Tech_Portfolio_Report.xlsx
 - Executive Summary sheet
 - Solver-Ready optimization model
 - What-If Analysis scenarios
 - Comprehensive data tables
 - Assumptions & Limitations
 - FF3, FF5, and Carhart loadings added to 'Factor Loadings' tab
2. Dashboard: Tech_Portfolio_Dashboard.png
 - Efficient Frontier, Correlation, Weights, Performance
 - Risk Metrics, Sensitivity, Return Distribution
 - CAPM, APT, FF3, FF5, Carhart Loadings
 - R-Squared Analysis & Portfolio Factor Exposure