```
!pip install simpy matplotlib

Requirement already satisfied: simpy in
/usr/local/lib/python3.12/dist-packages (4.1.1)
Requirement already satisfied: matplotlib in
/usr/local/lib/python3.12/dist-packages (3.10.0)
Requirement already satisfied: contourpy>=1.0.1 in
/usr/local/lib/python3.12/dist-packages (from matplotlib) (1.3.3)
Requirement already satisfied: cycler>=0.10 in
/usr/local/lib/python3.12/dist-packages (from matplotlib) (0.12.1)
Requirement already satisfied: fonttools>=4.22.0 in
/usr/local/lib/python3.12/dist-packages (from matplotlib) (4.60.1)
Requirement already satisfied: kiwisolver>=1.3.1 in
/usr/local/lib/python3.12/dist-packages (from matplotlib) (1.4.9)
Requirement already satisfied: numpy>=1.23 in
/usr/local/lib/python3.12/dist-packages (from matplotlib) (2.0.2)
Requirement already satisfied: packaging>=20.0 in
/usr/local/lib/python3.12/dist-packages (from matplotlib) (25.0)
Requirement already satisfied: pillow>=8 in
/usr/local/lib/python3.12/dist-packages (from matplotlib) (11.3.0)
Requirement already satisfied: pyparsing>=2.3.1 in
/usr/local/lib/python3.12/dist-packages (from matplotlib) (3.2.5)
Requirement already satisfied: python-dateutil>=2.7 in
/usr/local/lib/python3.12/dist-packages (from matplotlib)
(2.9.0.post0)
Requirement already satisfied: six>=1.5 in
/usr/local/lib/python3.12/dist-packages (from python-dateutil>=2.7-
>matplotlib) (1.17.0)

!pip install mesa==2.1.1

Collecting mesa==2.1.1
  Downloading Mesa-2.1.1-py3-none-any.whl.metadata (7.3 kB)
Requirement already satisfied: click in
/usr/local/lib/python3.12/dist-packages (from mesa==2.1.1) (8.3.0)
Collecting cookiecutter (from mesa==2.1.1)
  Downloading cookiecutter-2.6.0-py3-none-any.whl.metadata (7.3 kB)
Requirement already satisfied: networkx in
/usr/local/lib/python3.12/dist-packages (from mesa==2.1.1) (3.5)
Requirement already satisfied: numpy in
/usr/local/lib/python3.12/dist-packages (from mesa==2.1.1) (2.0.2)
Requirement already satisfied: pandas in
/usr/local/lib/python3.12/dist-packages (from mesa==2.1.1) (2.2.2)
Collecting solara (from mesa==2.1.1)
  Downloading solara-1.53.0-py3-none-any.whl.metadata (10 kB)
Requirement already satisfied: tornado in
/usr/local/lib/python3.12/dist-packages (from mesa==2.1.1) (6.5.1)
Requirement already satisfied: tqdm in /usr/local/lib/python3.12/dist-
packages (from mesa==2.1.1) (4.67.1)
Collecting binaryornot>=0.4.4 (from cookiecutter->mesa==2.1.1)
```

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  Downloading binaryornot-0.4.4-py2.py3-none-any.whl.metadata (6.0 kB)
Requirement already satisfied: Jinja2<4.0.0,>=2.7 in
/usr/local/lib/python3.12/dist-packages (from cookiecutter-
>mesa==2.1.1) (3.1.6)
Requirement already satisfied: pyyaml>=5.3.1 in
/usr/local/lib/python3.12/dist-packages (from cookiecutter-
>mesa==2.1.1) (6.0.3)
Requirement already satisfied: python-slugify>=4.0.0 in
/usr/local/lib/python3.12/dist-packages (from cookiecutter-
>mesa==2.1.1) (8.0.4)
Requirement already satisfied: requests>=2.23.0 in
/usr/local/lib/python3.12/dist-packages (from cookiecutter-
>mesa==2.1.1) (2.32.4)
Requirement already satisfied: arrow in
/usr/local/lib/python3.12/dist-packages (from cookiecutter-
>mesa==2.1.1) (1.4.0)
Requirement already satisfied: rich in /usr/local/lib/python3.12/dist-
packages (from cookiecutter->mesa==2.1.1) (13.9.4)
Requirement already satisfied: python-dateutil>=2.8.2 in
/usr/local/lib/python3.12/dist-packages (from pandas->mesa==2.1.1)
(2.9.0.post0)
Requirement already satisfied: pytz>=2020.1 in
/usr/local/lib/python3.12/dist-packages (from pandas->mesa==2.1.1)
(2025.2)
Requirement already satisfied: tzdata>=2022.7 in
/usr/local/lib/python3.12/dist-packages (from pandas->mesa==2.1.1)
(2025.2)
Collecting solara-server==1.53.0 (from solara-
server[dev,starlette]==1.53.0->solara->mesa==2.1.1)
  Downloading solara_server-1.53.0-py3-none-any.whl.metadata (2.9 kB)
Collecting solara-ui==1.53.0 (from solara-ui[all]==1.53.0->solara-
>mesa==2.1.1)
  Downloading solara_ui-1.53.0-py3-none-any.whl.metadata (7.5 kB)
Requirement already satisfied: filelock in
/usr/local/lib/python3.12/dist-packages (from solara-server==1.53.0-
>solara-server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (3.20.0)
Requirement already satisfied: ipykernel!=7.0.0,!=7.0.1 in
/usr/local/lib/python3.12/dist-packages (from solara-server==1.53.0-
>solara-server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (6.17.1)
Requirement already satisfied: jupyter-client in
/usr/local/lib/python3.12/dist-packages (from solara-server==1.53.0-
>solara-server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (7.4.9)
Requirement already satisfied: nbformat in
/usr/local/lib/python3.12/dist-packages (from solara-server==1.53.0-
>solara-server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (5.10.4)
Collecting rich-click (from solara-server==1.53.0->solara-
server[dev,starlette]==1.53.0->solara->mesa==2.1.1)
  Downloading rich_click-1.9.3-py3-none-any.whl.metadata (8.6 kB)
Requirement already satisfied: watchdog in
```

```
/usr/local/lib/python3.12/dist-packages (from solara-
server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (6.0.0)
Collecting watchfiles (from solara-server[dev,starlette]==1.53.0-
>solara->mesa==2.1.1)
  Downloading watchfiles-1.1.1-cp312-cp312-
manylinux_2_17_x86_64.manylinux2014_x86_64.whl.metadata (4.9 kB)
Requirement already satisfied: starlette in
/usr/local/lib/python3.12/dist-packages (from solara-
server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (0.48.0)
Requirement already satisfied: uvicorn in
/usr/local/lib/python3.12/dist-packages (from solara-
server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (0.38.0)
Requirement already satisfied: websockets in
/usr/local/lib/python3.12/dist-packages (from solara-
server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (15.0.1)
Requirement already satisfied: humanize in
/usr/local/lib/python3.12/dist-packages (from solara-ui==1.53.0-
>solara-ui[all]==1.53.0->solara->mesa==2.1.1) (4.14.0)
Collecting ipyvue>=1.9.0 (from solara-ui==1.53.0->solara-
ui[all]==1.53.0->solara->mesa==2.1.1)
  Downloading ipyvue-1.11.3-py2.py3-none-any.whl.metadata (987 bytes)
Collecting ipyvuetify>=1.6.10 (from solara-ui==1.53.0->solara-
ui[all]==1.53.0->solara->mesa==2.1.1)
  Downloading ipyvuetify-1.11.3-py2.py3-none-any.whl.metadata (7.5 kB)
Requirement already satisfied: ipywidgets>=7.7 in
/usr/local/lib/python3.12/dist-packages (from solara-ui==1.53.0-
>solara-ui[all]==1.53.0->solara->mesa==2.1.1) (7.7.1)
Collecting reacton>=1.9 (from solara-ui==1.53.0->solara-
ui[all]==1.53.0->solara->mesa==2.1.1)
  Downloading reacton-1.9.1-py2.py3-none-any.whl.metadata (3.1 kB)
Requirement already satisfied: cachetools in
/usr/local/lib/python3.12/dist-packages (from solara-ui[all]==1.53.0-
>solara->mesa==2.1.1) (5.5.2)
Requirement already satisfied: markdown in
/usr/local/lib/python3.12/dist-packages (from solara-ui[all]==1.53.0-
>solara->mesa==2.1.1) (3.9)
Requirement already satisfied: pillow in
/usr/local/lib/python3.12/dist-packages (from solara-ui[all]==1.53.0-
>solara->mesa==2.1.1) (11.3.0)
Requirement already satisfied: pygments in
/usr/local/lib/python3.12/dist-packages (from solara-ui[all]==1.53.0-
>solara->mesa==2.1.1) (2.19.2)
Collecting pymdown-extensions (from solara-ui[all]==1.53.0->solara-
>mesa==2.1.1)
  Downloading pymdown_extensions-10.16.1-py3-none-any.whl.metadata
(3.1 kB)
Requirement already satisfied: chardet>=3.0.2 in
/usr/local/lib/python3.12/dist-packages (from binaryornot>=0.4.4-
>cookiecutter->mesa==2.1.1) (5.2.0)
```

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Requirement already satisfied: MarkupSafe>=2.0 in
/usr/local/lib/python3.12/dist-packages (from Jinja2<4.0.0,>=2.7-
>cookiecutter->mesa==2.1.1) (3.0.3)
Requirement already satisfied: six>=1.5 in
/usr/local/lib/python3.12/dist-packages (from python-dateutil>=2.8.2-
>pandas->mesa==2.1.1) (1.17.0)
Requirement already satisfied: text-unidecode>=1.3 in
/usr/local/lib/python3.12/dist-packages (from python-slugify>=4.0.0-
>cookiecutter->mesa==2.1.1) (1.3)
Requirement already satisfied: charset_normalizer<4,>=2 in
/usr/local/lib/python3.12/dist-packages (from requests>=2.23.0-
>cookiecutter->mesa==2.1.1) (3.4.4)
Requirement already satisfied: idna<4,>=2.5 in
/usr/local/lib/python3.12/dist-packages (from requests>=2.23.0-
>cookiecutter->mesa==2.1.1) (3.11)
Requirement already satisfied: urllib3<3,>=1.21.1 in
/usr/local/lib/python3.12/dist-packages (from requests>=2.23.0-
>cookiecutter->mesa==2.1.1) (2.5.0)
Requirement already satisfied: certifi>=2017.4.17 in
/usr/local/lib/python3.12/dist-packages (from requests>=2.23.0-
>cookiecutter->mesa==2.1.1) (2025.10.5)
Requirement already satisfied: markdown-it-py>=2.2.0 in
/usr/local/lib/python3.12/dist-packages (from rich->cookiecutter-
>mesa==2.1.1) (4.0.0)
Requirement already satisfied: debugpy>=1.0 in
/usr/local/lib/python3.12/dist-packages (from ipykernel!=7.0.0,!
=7.0.1->solara-server==1.53.0->solara-server[dev,starlette]==1.53.0-
>solara->mesa==2.1.1) (1.8.15)
Requirement already satisfied: ipython>=7.23.1 in
/usr/local/lib/python3.12/dist-packages (from ipykernel!=7.0.0,!
=7.0.1->solara-server==1.53.0->solara-server[dev,starlette]==1.53.0-
>solara->mesa==2.1.1) (7.34.0)
Requirement already satisfied: matplotlib-inline>=0.1 in
/usr/local/lib/python3.12/dist-packages (from ipykernel!=7.0.0,!
=7.0.1->solara-server==1.53.0->solara-server[dev,starlette]==1.53.0-
>solara->mesa==2.1.1) (0.1.7)
Requirement already satisfied: nest-asyncio in
/usr/local/lib/python3.12/dist-packages (from ipykernel!=7.0.0,!
=7.0.1->solara-server==1.53.0->solara-server[dev,starlette]==1.53.0-
>solara->mesa==2.1.1) (1.6.0)
Requirement already satisfied: packaging in
/usr/local/lib/python3.12/dist-packages (from ipykernel!=7.0.0,!
=7.0.1->solara-server==1.53.0->solara-server[dev,starlette]==1.53.0-
>solara->mesa==2.1.1) (25.0)
Requirement already satisfied: psutil in
/usr/local/lib/python3.12/dist-packages (from ipykernel!=7.0.0,!
=7.0.1->solara-server==1.53.0->solara-server[dev,starlette]==1.53.0-
>solara->mesa==2.1.1) (5.9.5)
Requirement already satisfied: pyzmq>=17 in
```

/usr/local/lib/python3.12/dist-packages (from ipykernel!=7.0.0,!
=7.0.1->solara-server==1.53.0->solara-server[dev,starlette]==1.53.0-
>solara->mesa==2.1.1) (26.2.1)
Requirement already satisfied: traitlets>=5.1.0 in
/usr/local/lib/python3.12/dist-packages (from ipykernel!=7.0.0,!
=7.0.1->solara-server==1.53.0->solara-server[dev,starlette]==1.53.0-
>solara->mesa==2.1.1) (5.7.1)
Requirement already satisfied: ipython-genutils~=0.2.0 in
/usr/local/lib/python3.12/dist-packages (from ipywidgets>=7.7->solara-
ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (0.2.0)
Requirement already satisfied: widgetsnbextension~=3.6.0 in
/usr/local/lib/python3.12/dist-packages (from ipywidgets>=7.7->solara-
ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (3.6.10)
Requirement already satisfied: jupyterlab-widgets>=1.0.0 in
/usr/local/lib/python3.12/dist-packages (from ipywidgets>=7.7->solara-
ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (3.0.15)
Requirement already satisfied: entrypoints in
/usr/local/lib/python3.12/dist-packages (from jupyter-client->solara-
server==1.53.0->solara-server[dev,starlette]==1.53.0->solara-
>mesa==2.1.1) (0.4)
Requirement already satisfied: jupyter-core>=4.9.2 in
/usr/local/lib/python3.12/dist-packages (from jupyter-client->solara-
server==1.53.0->solara-server[dev,starlette]==1.53.0->solara-
>mesa==2.1.1) (5.9.1)
Requirement already satisfied: mdurl~=0.1 in
/usr/local/lib/python3.12/dist-packages (from markdown-it-py>=2.2.0-
>rich->cookiecutter->mesa==2.1.1) (0.1.2)
Requirement already satisfied: typing-extensions>=4.1.1 in
/usr/local/lib/python3.12/dist-packages (from reacton>=1.9->solara-
ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (4.15.0)
Requirement already satisfied: fastjsonschema>=2.15 in
/usr/local/lib/python3.12/dist-packages (from nbformat->solara-
server==1.53.0->solara-server[dev,starlette]==1.53.0->solara-
>mesa==2.1.1) (2.21.2)
Requirement already satisfied: jsonschema>=2.6 in
/usr/local/lib/python3.12/dist-packages (from nbformat->solara-
server==1.53.0->solara-server[dev,starlette]==1.53.0->solara-
>mesa==2.1.1) (4.25.1)
Requirement already satisfied: anyio<5,>=3.6.2 in
/usr/local/lib/python3.12/dist-packages (from starlette->solara-
server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (4.11.0)
Requirement already satisfied: h11>=0.8 in
/usr/local/lib/python3.12/dist-packages (from uvicorn->solara-
server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (0.16.0)
Requirement already satisfied: sniffio>=1.1 in
/usr/local/lib/python3.12/dist-packages (from anyio<5,>=3.6.2-
>starlette->solara-server[dev,starlette]==1.53.0->solara->mesa==2.1.1)
(1.3.1)
Requirement already satisfied: setuptools>=18.5 in

```
/usr/local/lib/python3.12/dist-packages (from ipython>=7.23.1-
>ipykernel!=7.0.0,!=7.0.1->solara-server==1.53.0->solara-
server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (75.2.0)
Collecting jedi>=0.16 (from ipython>=7.23.1->ipykernel!=7.0.0,!=7.0.1-
>solara-server==1.53.0->solara-server[dev,starlette]==1.53.0->solara-
>mesa==2.1.1)
  Downloading jedi-0.19.2-py2.py3-none-any.whl.metadata (22 kB)
Requirement already satisfied: decorator in
/usr/local/lib/python3.12/dist-packages (from ipython>=7.23.1-
>ipykernel!=7.0.0,!=7.0.1->solara-server==1.53.0->solara-
server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (4.4.2)
Requirement already satisfied: pickleshare in
/usr/local/lib/python3.12/dist-packages (from ipython>=7.23.1-
>ipykernel!=7.0.0,!=7.0.1->solara-server==1.53.0->solara-
server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (0.7.5)
Requirement already satisfied: prompt-toolkit!=3.0.0,!
=3.0.1,<3.1.0,>=2.0.0 in /usr/local/lib/python3.12/dist-packages (from
ipython>=7.23.1->ipykernel!=7.0.0,!=7.0.1->solara-server==1.53.0-
>solara-server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (3.0.52)
Requirement already satisfied: backcall in
/usr/local/lib/python3.12/dist-packages (from ipython>=7.23.1-
>ipykernel!=7.0.0,!=7.0.1->solara-server==1.53.0->solara-
server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (0.2.0)
Requirement already satisfied: pexpect>4.3 in
/usr/local/lib/python3.12/dist-packages (from ipython>=7.23.1-
>ipykernel!=7.0.0,!=7.0.1->solara-server==1.53.0->solara-
server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (4.9.0)
Requirement already satisfied: attrs>=22.2.0 in
/usr/local/lib/python3.12/dist-packages (from jsonschema>=2.6-
>nbformat->solara-server==1.53.0->solara-
server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (25.4.0)
Requirement already satisfied: jsonschema-specifications>=2023.03.6 in
/usr/local/lib/python3.12/dist-packages (from jsonschema>=2.6-
>nbformat->solara-server==1.53.0->solara-
server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (2025.9.1)
Requirement already satisfied: referencing>=0.28.4 in
/usr/local/lib/python3.12/dist-packages (from jsonschema>=2.6-
>nbformat->solara-server==1.53.0->solara-
server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (0.37.0)
Requirement already satisfied: rpds-py>=0.7.1 in
/usr/local/lib/python3.12/dist-packages (from jsonschema>=2.6-
>nbformat->solara-server==1.53.0->solara-
server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (0.27.1)
Requirement already satisfied: platformdirs>=2.5 in
/usr/local/lib/python3.12/dist-packages (from jupyter-core>=4.9.2-
>jupyter-client->solara-server==1.53.0->solara-
server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (4.5.0)
Requirement already satisfied: notebook>=4.4.1 in
/usr/local/lib/python3.12/dist-packages (from
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widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (6.5.7)
Requirement already satisfied: parso<0.9.0,>=0.8.4 in /usr/local/lib/python3.12/dist-packages (from jedi>=0.16->ipython>=7.23.1->ipykernel!=7.0.0,!=7.0.1->solara-server==1.53.0->solara-server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (0.8.5)
Requirement already satisfied: argon2-cffi in /usr/local/lib/python3.12/dist-packages (from notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (25.1.0)
Requirement already satisfied: nbconvert>=5 in /usr/local/lib/python3.12/dist-packages (from notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (7.16.6)
Requirement already satisfied: Send2Trash>=1.8.0 in /usr/local/lib/python3.12/dist-packages (from notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (1.8.3)
Requirement already satisfied: terminado>=0.8.3 in /usr/local/lib/python3.12/dist-packages (from notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (0.18.1)
Requirement already satisfied: prometheus-client in /usr/local/lib/python3.12/dist-packages (from notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (0.23.1)
Requirement already satisfied: nbclassic>=0.4.7 in /usr/local/lib/python3.12/dist-packages (from notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (1.3.3)
Requirement already satisfied: ptyprocess>=0.5 in /usr/local/lib/python3.12/dist-packages (from pexpect>4.3->ipython>=7.23.1->ipykernel!=7.0.0,!=7.0.1->solara-server==1.53.0->solara-server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (0.7.0)
Requirement already satisfied: wcwidth in /usr/local/lib/python3.12/dist-packages (from prompt-toolkit!=3.0.0,!=3.0.1,<3.1.0,>=2.0.0->ipython>=7.23.1->ipykernel!=7.0.0,!=7.0.1->solara-server==1.53.0->solara-server[dev,starlette]==1.53.0->solara->mesa==2.1.1) (0.2.14)
Requirement already satisfied: notebook-shim>=0.2.3 in /usr/local/lib/python3.12/dist-packages (from nbclassic>=0.4.7->notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (0.2.4)
Requirement already satisfied: beautifulsoup4 in /usr/local/lib/python3.12/dist-packages (from nbconvert>=5->notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (4.13.5)
Requirement already satisfied: bleach!=5.0.0 in /usr/local/lib/python3.12/dist-packages (from bleach[css]!=5.0.0-

>nbconvert>=5->notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (6.2.0)
Requirement already satisfied: defusedxml in /usr/local/lib/python3.12/dist-packages (from nbconvert>=5->notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (0.7.1)
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Requirement already satisfied: mistune<4,>=2.0.3 in /usr/local/lib/python3.12/dist-packages (from nbconvert>=5->notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (3.1.4)
Requirement already satisfied: nbclient>=0.5.0 in /usr/local/lib/python3.12/dist-packages (from nbconvert>=5->notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (0.10.2)
Requirement already satisfied: pandocfilters>=1.4.1 in /usr/local/lib/python3.12/dist-packages (from nbconvert>=5->notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (1.5.1)
Requirement already satisfied: argon2-cffi-bindings in /usr/local/lib/python3.12/dist-packages (from argon2-cffi->notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (25.1.0)
Requirement already satisfied: webencodings in /usr/local/lib/python3.12/dist-packages (from bleach!=5.0.0->bleach[css]!=5.0.0->nbconvert>=5->notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (0.5.1)
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Requirement already satisfied: cffi>=1.0.1 in /usr/local/lib/python3.12/dist-packages (from argon2-cffi-bindings->argon2-cffi->notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (2.0.0)
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>ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara-
>mesa==2.1.1) (2.8)
Requirement already satisfied: pycparser in
/usr/local/lib/python3.12/dist-packages (from cffi>=1.0.1->argon2-
cffi-bindings->argon2-cffi->notebook>=4.4.1-
>widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0-
>solara-ui[all]==1.53.0->solara->mesa==2.1.1) (2.23)
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>solara-ui[all]==1.53.0->solara->mesa==2.1.1) (0.12.0)
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/usr/local/lib/python3.12/dist-packages (from jupyter-server<3,>=1.8-
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>solara-ui[all]==1.53.0->solara->mesa==2.1.1) (0.5.3)
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>solara-ui[all]==1.53.0->solara->mesa==2.1.1) (7.7.0)
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>solara-ui[all]==1.53.0->solara->mesa==2.1.1) (1.9.0)
Requirement already satisfied: python-json-logger>=2.0.4 in
/usr/local/lib/python3.12/dist-packages (from jupyter-events>=0.9.0-
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>notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-
ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (4.0.0)
Requirement already satisfied: rfc3339-validator in
/usr/local/lib/python3.12/dist-packages (from jupyter-events>=0.9.0-
>jupyter-server<3,>=1.8->notebook-shim>=0.2.3->nbclassic>=0.4.7-
>notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-
ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (0.1.4)
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/usr/local/lib/python3.12/dist-packages (from jupyter-events>=0.9.0-
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>notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-
ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (0.1.1)
Requirement already satisfied: fqdn in /usr/local/lib/python3.12/dist-
packages (from jsonschema[format-nongpl]>=4.18.0->jupyter-
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>nbclassic>=0.4.7->notebook>=4.4.1->widgetsnbextension~=3.6.0-
>ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara-
>mesa==2.1.1) (1.5.1)
```

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Requirement already satisfied: jsonpointer>1.13 in /usr/local/lib/python3.12/dist-packages (from jsonschema[format-nongpl]>=4.18.0->jupyter-events>=0.9.0->jupyter-server<3,>=1.8->notebook-shim>=0.2.3->nbclassic>=0.4.7->notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (3.0.0)
Requirement already satisfied: rfc3987-syntax>=1.1.0 in /usr/local/lib/python3.12/dist-packages (from jsonschema[format-nongpl]>=4.18.0->jupyter-events>=0.9.0->jupyter-server<3,>=1.8->notebook-shim>=0.2.3->nbclassic>=0.4.7->notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (1.1.0)
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Requirement already satisfied: webcolors>=24.6.0 in /usr/local/lib/python3.12/dist-packages (from jsonschema[format-nongpl]>=4.18.0->jupyter-events>=0.9.0->jupyter-server<3,>=1.8->notebook-shim>=0.2.3->nbclassic>=0.4.7->notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (24.11.1)
Requirement already satisfied: lark>=1.2.2 in /usr/local/lib/python3.12/dist-packages (from rfc3987-syntax>=1.1.0->jsonschema[format-nongpl]>=4.18.0->jupyter-events>=0.9.0->jupyter-server<3,>=1.8->notebook-shim>=0.2.3->nbclassic>=0.4.7->notebook>=4.4.1->widgetsnbextension~=3.6.0->ipywidgets>=7.7->solara-ui==1.53.0->solara-ui[all]==1.53.0->solara->mesa==2.1.1) (1.3.0)
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down-extensions, jedi, binaryornot, watchfiles, rich-click,
cookiecutter, reacton, ipyvue, ipyvuetify, solara-ui, solara-server,
solara, mesa
  Attempting uninstall: mesa
    Found existing installation: Mesa 3.3.0
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1.53.0 solara-ui-1.53.0 watchfiles-1.1.1
```

Question 1

```python
# pip install simpy

import simpy
import random

# Simulation parameters
RANDOM_SEED = 42
NUM_PACKETS = 10
PROC_DELAY = 2  # Processing time per packet
random.seed(RANDOM_SEED)

# Define a packet process
def packet(env, name, routers):
    start_time = env.now
    print(f"{name} generated at time {start_time}")

    for router in routers:
        with router.request() as req:
            yield req
            yield env.timeout(PROC_DELAY)
            print(f"{name} processed by {router.name} at time
{env.now}")

    end_time = env.now
    print(f"{name} completed at {end_time}, total delay = {end_time -
start_time}")

# Generate packets and send them through routers
```

```python
def packet_generator(env, routers):
    for i in range(NUM_PACKETS):
        yield env.timeout(random.randint(1, 3))
        env.process(packet(env, f"Packet_{i}", routers))

# Initialize environment and routers
env = simpy.Environment()
routers = [simpy.Resource(env, capacity=1) for _ in range(3)]
for i, r in enumerate(routers):
    r.name = f"Router_{i+1}"

# Run simulation
env.process(packet_generator(env, routers))
env.run()
```

```
Packet_0 generated at time 3
Packet_1 generated at time 4
Packet_0 processed by Router_1 at time 5
Packet_2 generated at time 5
Packet_0 processed by Router_2 at time 7
Packet_1 processed by Router_1 at time 7
Packet_3 generated at time 8
Packet_0 processed by Router_3 at time 9
Packet_0 completed at 9, total delay = 6
Packet_1 processed by Router_2 at time 9
Packet_2 processed by Router_1 at time 9
Packet_4 generated at time 10
Packet_1 processed by Router_3 at time 11
Packet_1 completed at 11, total delay = 7
Packet_2 processed by Router_2 at time 11
Packet_3 processed by Router_1 at time 11
Packet_5 generated at time 11
Packet_6 generated at time 12
Packet_2 processed by Router_3 at time 13
Packet_2 completed at 13, total delay = 8
Packet_3 processed by Router_2 at time 13
Packet_4 processed by Router_1 at time 13
Packet_7 generated at time 13
Packet_3 processed by Router_3 at time 15
Packet_3 completed at 15, total delay = 7
Packet_4 processed by Router_2 at time 15
Packet_5 processed by Router_1 at time 15
Packet_8 generated at time 16
Packet_4 processed by Router_3 at time 17
Packet_4 completed at 17, total delay = 7
Packet_5 processed by Router_2 at time 17
Packet_6 processed by Router_1 at time 17
Packet_9 generated at time 17
Packet_5 processed by Router_3 at time 19
Packet_5 completed at 19, total delay = 8
```

```
Packet_6 processed by Router_2 at time 19
Packet_7 processed by Router_1 at time 19
Packet_6 processed by Router_3 at time 21
Packet_6 completed at 21, total delay = 9
Packet_7 processed by Router_2 at time 21
Packet_8 processed by Router_1 at time 21
Packet_7 processed by Router_3 at time 23
Packet_7 completed at 23, total delay = 10
Packet_8 processed by Router_2 at time 23
Packet_9 processed by Router_1 at time 23
Packet_8 processed by Router_3 at time 25
Packet_8 completed at 25, total delay = 9
Packet_9 processed by Router_2 at time 25
Packet_9 processed by Router_3 at time 27
Packet_9 completed at 27, total delay = 10
```

Question 2

```python
from mesa import Agent, Model
from mesa.time import SimultaneousActivation
from mesa.datacollection import DataCollector
import matplotlib.pyplot as plt
import random

# ------------------------------
# Router Agent
# ------------------------------
class RouterAgent(Agent):
    def __init__(self, unique_id, model, base_capacity=10):
        super().__init__(unique_id, model)
        self.queue = 0
        self.capacity = base_capacity      # packets per step
        self.throughput = 0                # packets processed per step

    def step(self):
        # Generate incoming packets (random)
        arrivals = random.randint(0, 20)
        self.queue += arrivals

        # Process up to capacity
        processed = min(self.queue, self.capacity)
        self.queue -= processed
        self.throughput = processed

        # Adaptive behavior: if congested, increase capacity slightly
        if self.queue > 30:
            self.capacity = min(self.capacity + 1, 25)
        elif self.queue < 5:
            self.capacity = max(self.capacity - 1, 5)
```

```python
    def advance(self):
        # nothing additional to finalize this step
        pass


# ------------------------------
# Network Model
# ------------------------------
class NetworkModel(Model):
    def __init__(self, num_routers=3, steps=100):
        self.num_routers = num_routers
        self.schedule = SimultaneousActivation(self)
        self.datacollector = DataCollector(
            model_reporters={
                "Avg_Queue": lambda m: sum(a.queue for a in
m.schedule.agents) / m.num_routers,
                "Avg_Capacity": lambda m: sum(a.capacity for a in
m.schedule.agents) / m.num_routers,
                "Avg_Throughput": lambda m: sum(a.throughput for a in
m.schedule.agents) / m.num_routers
            }
        )

        # Create router agents
        for i in range(num_routers):
            router = RouterAgent(i, self)
            self.schedule.add(router)

        self.steps = steps

    def step(self):
        self.datacollector.collect(self)
        self.schedule.step()


# ------------------------------
# Run the Simulation
# ------------------------------
model = NetworkModel(num_routers=3, steps=200)

for i in range(model.steps):
    model.step()

results = model.datacollector.get_model_vars_dataframe()

# ------------------------------
# Visualization
# ------------------------------
plt.figure(figsize=(10,5))
```
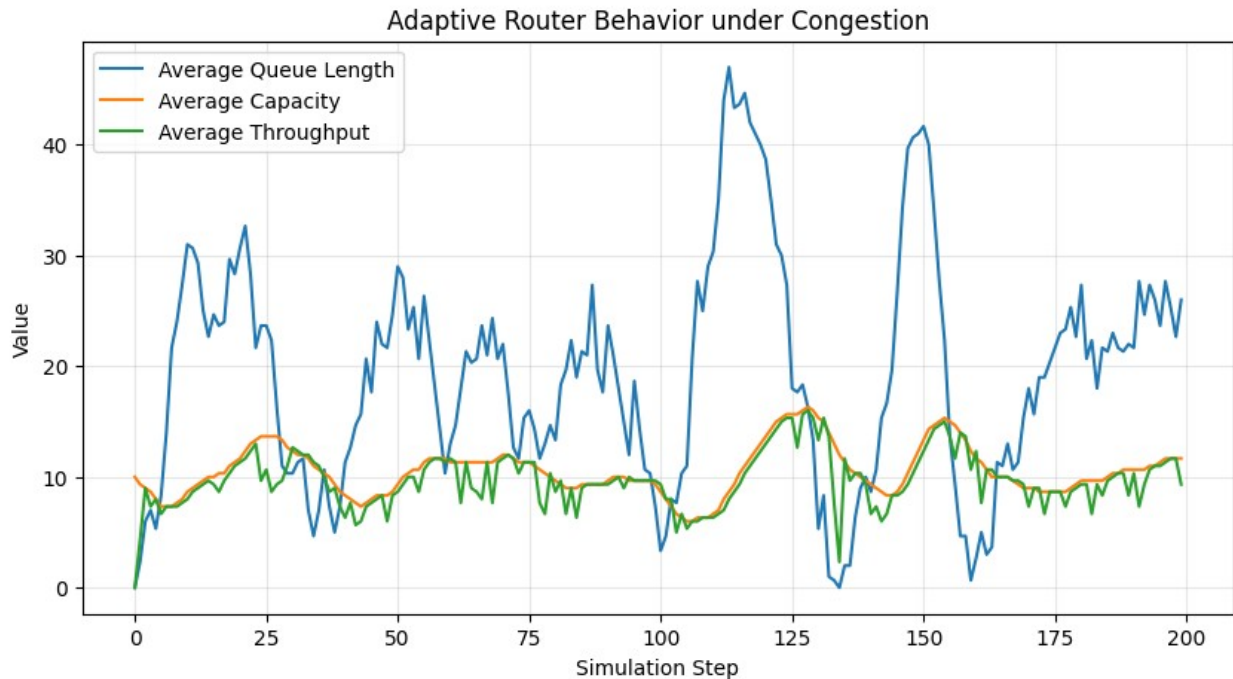
```python
plt.plot(results["Avg_Queue"], label="Average Queue Length")
plt.plot(results["Avg_Capacity"], label="Average Capacity")
plt.plot(results["Avg_Throughput"], label="Average Throughput")
plt.title("Adaptive Router Behavior under Congestion")
plt.xlabel("Simulation Step")
plt.ylabel("Value")
plt.legend()
plt.grid(True, alpha=0.3)
plt.show()
```


Question 3

```python
# ================================================================
# PRACTICAL 3: Predictive Optimization with AI
# ================================================================
# Objective: Use ML to predict traffic and optimize routing.
# Steps:
# 1. Collect data
# 2. Train regression model
# 3. Integrate prediction logic
# 4. Evaluate improvements
# ================================================================


# -----------------------------
# Imports
# -----------------------------
import numpy as np
import pandas as pd
```

```python
import matplotlib.pyplot as plt
from sklearn.model_selection import train_test_split
from sklearn.linear_model import LinearRegression
from sklearn.metrics import mean_absolute_error, r2_score

# -----------------------------
# Step 1: Collect / Simulate Data
# -----------------------------
np.random.seed(42)
time = np.arange(0, 200, 1)

# Simulate network traffic data
traffic = 50 + 10 * np.sin(time / 10) + np.random.normal(0, 3,
len(time))
capacity = 60 + 5 * np.sin(time / 15)
delay = np.maximum(0, (traffic - capacity) * 0.5)

# Create DataFrame
df = pd.DataFrame({
    "Time": time,
    "Traffic": traffic,
    "Capacity": capacity,
    "Delay": delay
})

# Visualize simulated network data
plt.figure(figsize=(8,4))
plt.plot(df["Time"], df["Traffic"], label="Traffic Load")
plt.plot(df["Time"], df["Capacity"], label="Router Capacity")
plt.plot(df["Time"], df["Delay"], label="Delay", linestyle="--")
plt.xlabel("Time (s)")
plt.ylabel("Packets / Delay")
plt.title("Simulated Network Data")
plt.legend()
plt.grid(True, alpha=0.3)
plt.show()

# -----------------------------
# Step 2: Train Regression Model
# -----------------------------
# Create lag features (previous time steps)
df["Traffic_t-1"] = df["Traffic"].shift(1)
df["Traffic_t-2"] = df["Traffic"].shift(2)
df.dropna(inplace=True)

# Define features and target
X = df[["Traffic_t-1", "Traffic_t-2", "Capacity"]]
y = df["Traffic"]

# Split data
```

```python
X_train, X_test, y_train, y_test = train_test_split(X, y,
test_size=0.2, random_state=42)

# Train regression model
model = LinearRegression()
model.fit(X_train, y_train)

# Predict and evaluate
y_pred = model.predict(X_test)
mae = mean_absolute_error(y_test, y_pred)
r2 = r2_score(y_test, y_pred)

print(f"□ Mean Absolute Error (MAE): {mae:.2f}")
print(f"□ R² Score: {r2:.2f}")

# Visualize actual vs predicted
plt.figure(figsize=(6,4))
plt.scatter(y_test, y_pred, alpha=0.7)
plt.xlabel("Actual Traffic")
plt.ylabel("Predicted Traffic")
plt.title("Traffic Prediction (Regression)")
plt.grid(True, alpha=0.3)
plt.show()

# -------------------------------
# Step 3: Integrate Prediction Logic (Optimization)
# -------------------------------
# Predict next-step traffic for all rows
df["Predicted_Traffic"] = model.predict(X)

# Adjust capacity proactively if congestion predicted
df["Optimized_Capacity"] = df.apply(
    lambda row: row["Capacity"] * 1.1 if row["Predicted_Traffic"] >
row["Capacity"] else row["Capacity"],
    axis=1
)

# Compute new optimized delay
df["Optimized_Delay"] = np.maximum(0, (df["Traffic"] -
df["Optimized_Capacity"]) * 0.5)

# Visualize delay improvement
plt.figure(figsize=(8,4))
plt.plot(df["Time"], df["Delay"], label="Original Delay")
plt.plot(df["Time"], df["Optimized_Delay"], label="Optimized Delay",
linestyle="--")
plt.title("Delay Reduction After Predictive Optimization")
plt.xlabel("Time (s)")
plt.ylabel("Delay")
plt.legend()
```
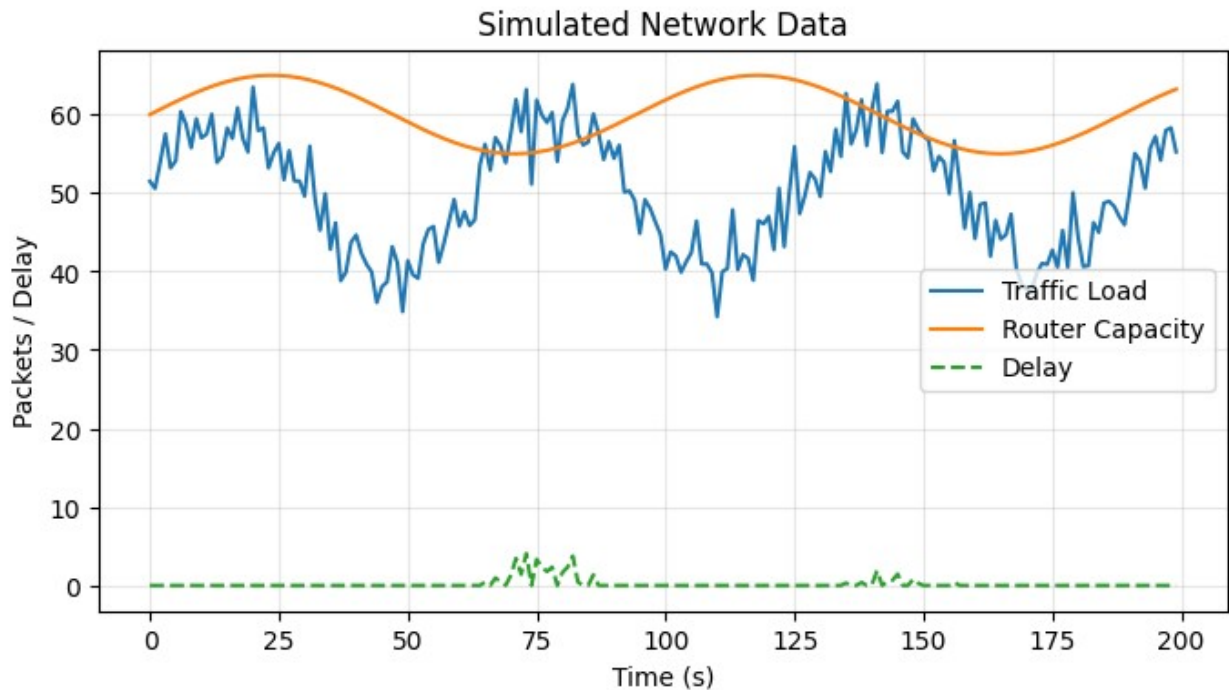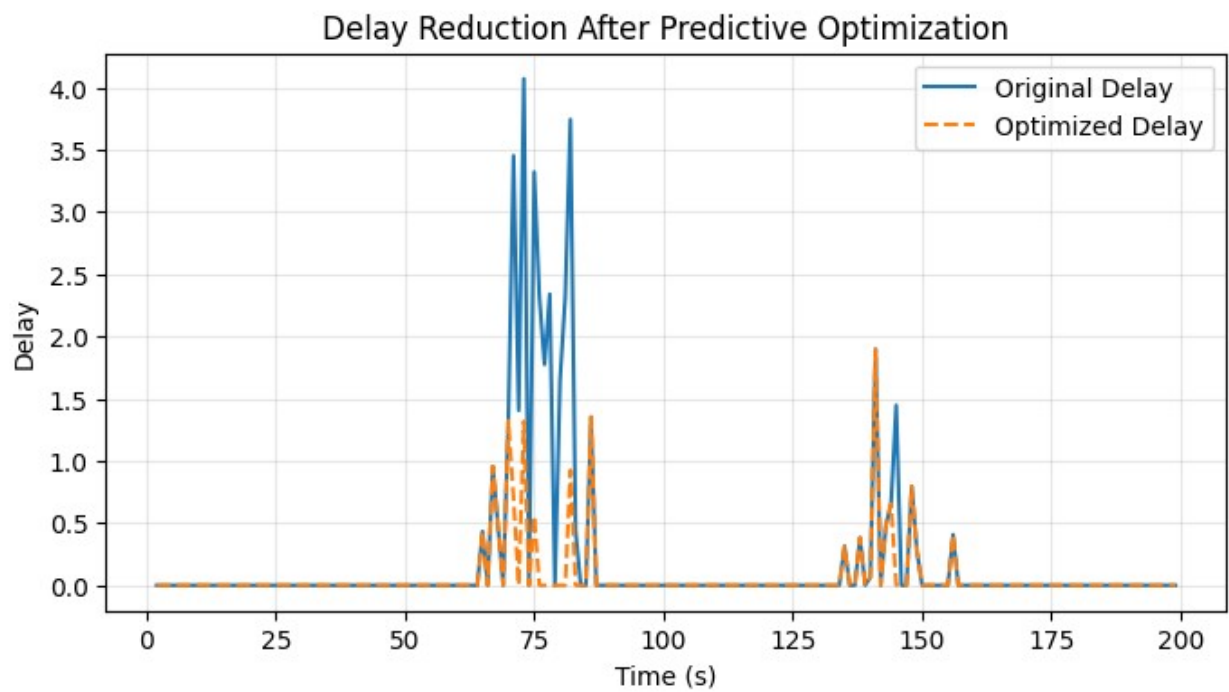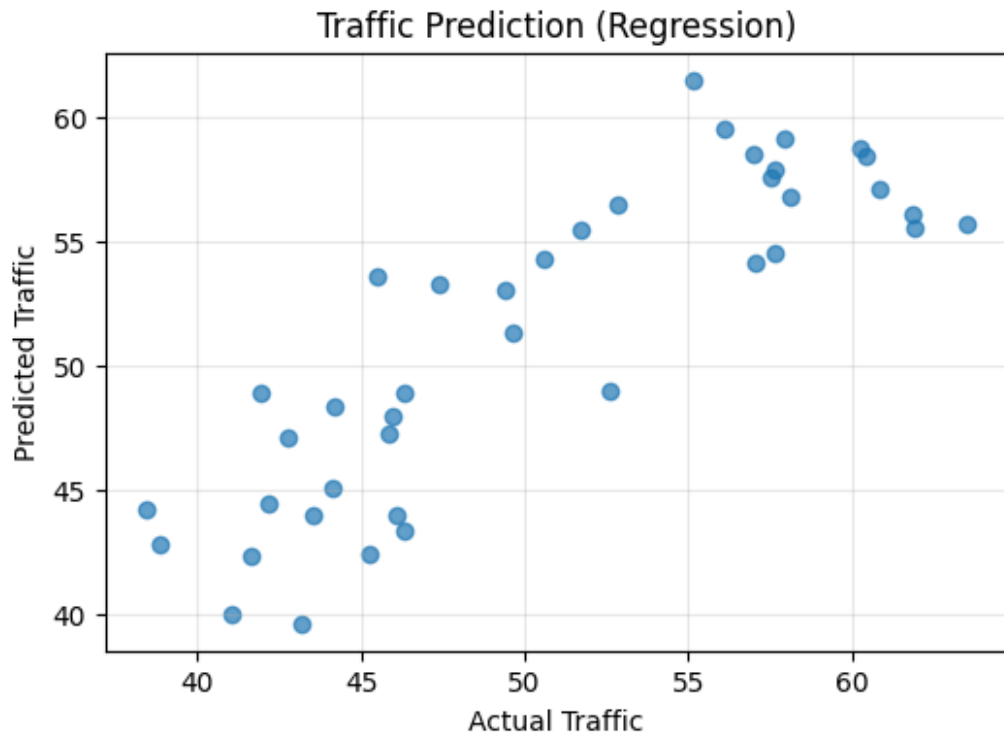
```
plt.grid(True, alpha=0.3)
plt.show()

# ------------------------------
# Step 4: Evaluate Improvements
# ------------------------------
avg_delay_before = df["Delay"].mean()
avg_delay_after = df["Optimized_Delay"].mean()
improvement = 100 * (avg_delay_before - avg_delay_after) /
avg_delay_before

print("□ Evaluation Results")
print(f"Average Delay Before: {avg_delay_before:.2f}")
print(f"Average Delay After:  {avg_delay_after:.2f}")
print(f"□ Improvement:        {improvement:.1f}%")
```


Simulated Network Data

```
□ Mean Absolute Error (MAE): 3.24
□ R² Score: 0.72
```

Traffic Prediction (Regression)

Delay Reduction After Predictive Optimization

```
 Evaluation Results
Average Delay Before: 0.19
Average Delay After:  0.07
 Improvement:        65.0%
```