Hochschule für
Technik und Wirtschaft
Dresden
University of Applied Sciences

Forschungs- und
Entwicklungsseminar
WS 20/21

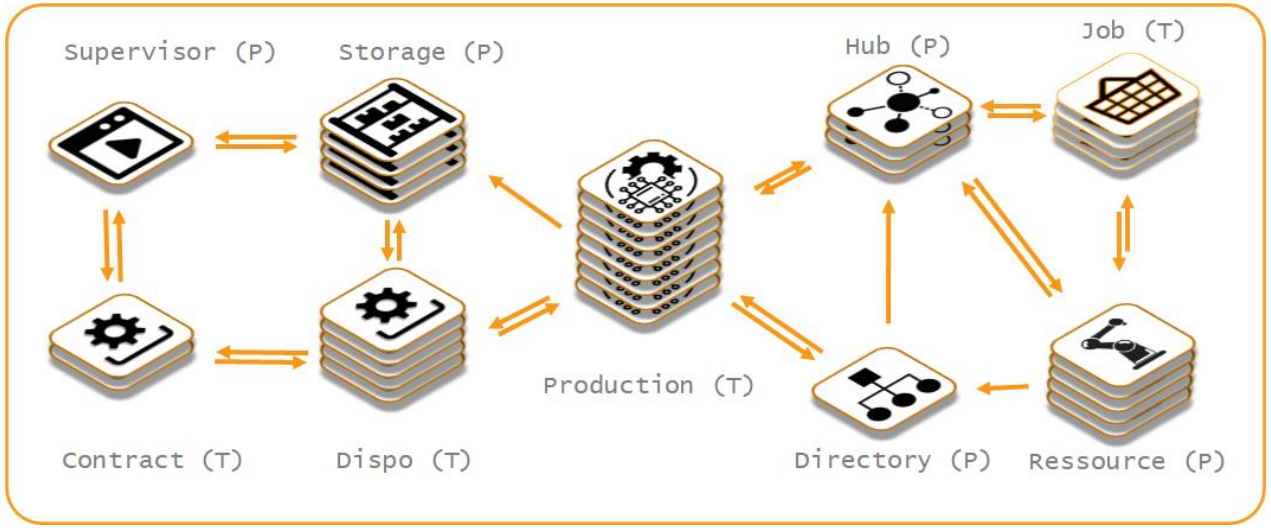
Machine Learning in der sich selbst organisierenden Produktion

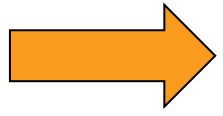
Referenten: Max Weickert
Max Schwerdtner

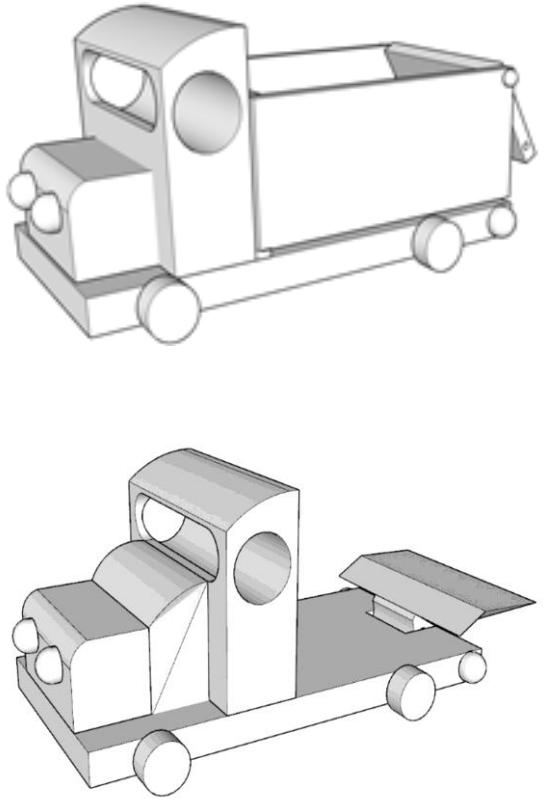
Datum: 18.01.2021

Erläuterung der Problemstellung

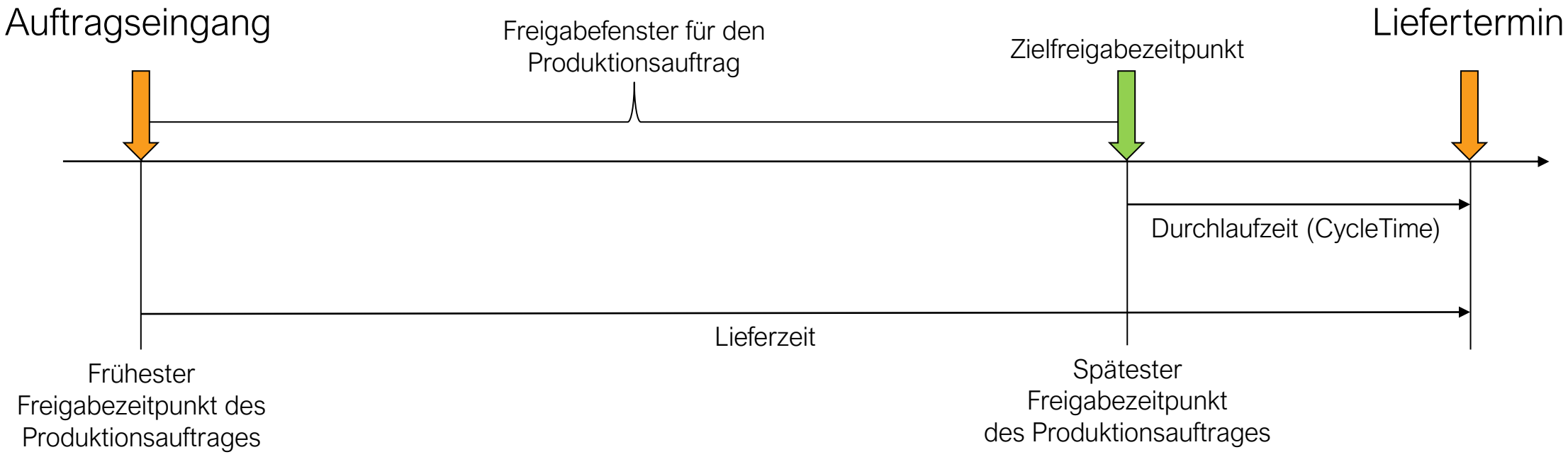
Was ist die SSOP?







Erläuterung der Problemstellung



Vorgehensweise zur Lösung der Problemstellung

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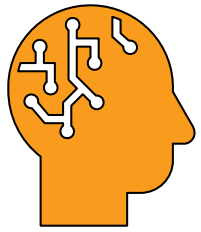
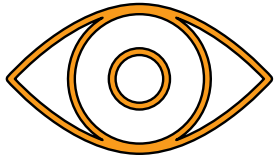
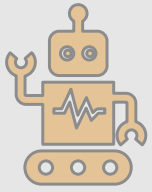


Machine Learning

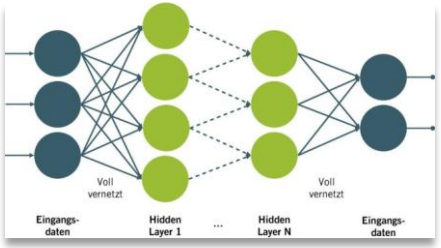


Supervised Learning

Unsupervised Learning



Reinforcement Learning



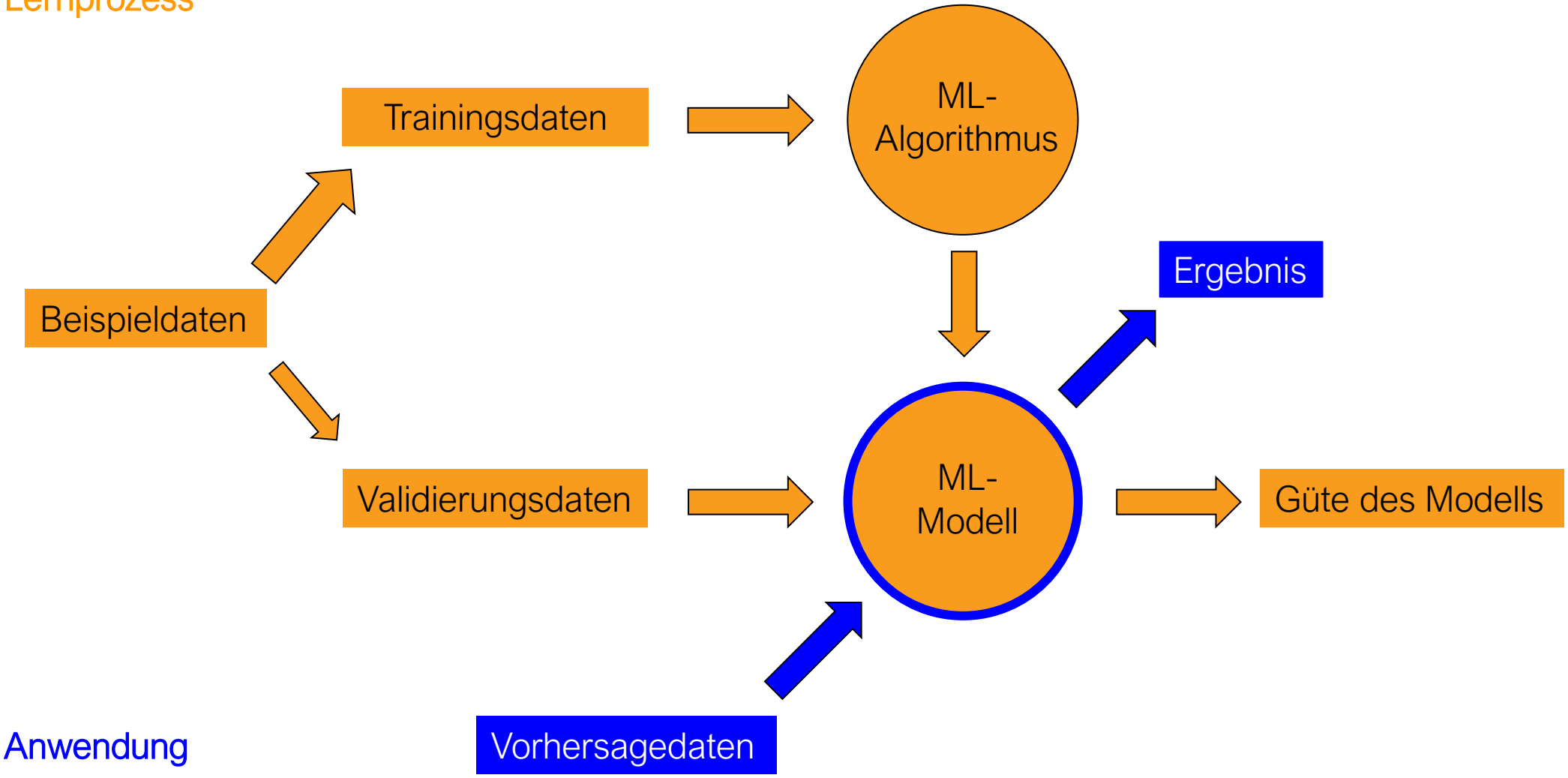
ML.NET

Adressiert Probleme der SSOP nicht

Keine „out of the box“ Integration

Supervised Learning

Lernprozess



Anwendung

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Korrelationsanalyse

Korrelation mit der CycleTime

Korrelation	Time	Idle:Assem	La	en	Idl	rillin	InDue	OverDue	New
Time	1	-0,0402	0	56	0,	1205	-0,08515	0,01681	-0,12644
Idle:Assemb	-0,0402	1	0	06	0,	3007	0,056257	0,469593	-0,00519
Lateness	0,703379	0,061262		33	-0	2623	-0,18399	0,058958	-0,17641
AssemblingC	0,024996	-0,48545	-	18	-0	,319	-0,00026	-0,29096	-0,12207
Idle:Assemb	0,035356	0,538106	0	1	0,	4472	-0,07068	0,433135	-0,04178
Idle:Drilling	0,021281	0,354384	-	79		0739	0,002532	0,266047	-0,04148
TotalSetup	0,059635	-0,43953	0	45	-0	4152	-0,0339	-0,28164	-0,13718
Idle:Drilling	-0,11205	0,263007		72	0	1	-0,03749	0,208881	0,067427
InDue	-0,08515	0,056257	-	58	0,	3749	1	-0,35835	-0,09634
OverDue	0,01681	0,469593	0	35	0,	3881	-0,35835	1	-0,10398
New	-0,12644	-0,00519	-	78	-0	7427	-0,09634	-0,10398	1
Product	-0,19501	-0,01035	-	57	0,	0278	0,067483	-0,02901	0,25371
AdherenceTo	0,004816	-0,44978	-	18	-0	0121	0,40156	-0,95901	0,138807
Idle:Assemb	0,027617	0,294283	0	51	0,	0361	-0,12561	0,565954	-0,06619
Idle:Assemb	0,18355	0,155839	0	23	0,	9942	0,005484	0,183518	-0,15042
Idle:Drilling	-0,06644	0,278679	-	13	0,	9141	0,010524	0,238829	0,019148

Time	0,882839814
Idle:Assembling	-0,006587485
Lateness	0,997637594
AssemblingOpe	-0,141851475
Idle:Assembling	0,180313071
Idle:Drilling Too	0,157674007
TotalSetup	-0,159253828
Idle:Drilling Too	0,10135359
InDue	-0,016744137
OverDue	0,061861848
New	-0,045952598
Product	-0,67372162
AdherenceToDu	-0,137682672
Idle:Assembling	0,077733549
Idle:Assembling	0,185653024
Idle:Drilling Too	0,081013811
TotalWork	0,130598494
Finished	0,004270916
OEE	0,12990943
CuttingOperato	-0,060056266
Idle:Assembling	0,236712828
Idle:Drilling Too	0,195816212
Assembling2	0,175105947

Assembling1	-0,00084644
Assembly	-0,94799926
Total	0,89407951
Idle:Cutting Tc	0,08510948
Idle:Cutting Tc	0,05711395
Worker2	0,15821874
OverDueTotal	0,94504994
Cutting1	-0,04896553
Worker3	0,21612601
Idle:Cutting Tc	-0,0027869
CycleTime	1
Idle:Assemblir	0,04596797
Consumab	0,52701318
Drilling1	-0,08699613
DrillingOperat	-0,1866261
Tardiness	0,89631063
Cutting2	0,00811704
Idle:Cutting Tc	0,00712345
Idle:Assemblir	0,2373574
Material	0,66226909
InDueTotal	0,88801836
Open	-0,0638786
Worker1	-0,04789451

Trainingsdatenaufbereitung

Ausgangspunkt: 12 Simulationen mit 8 Wochen Simulationszeit

Time	Lateness	Assembly	Total	CycleTime	Consumab	Material	InDueTotal
3360	-1045.2	4.89579464	20	1362.05	19534.8314	3051672.43	20
3840	-762.69697	4.57235547	33	1596.36364	19910.4301	3139436.86	33
4320	-705.461538	4.29517014	39	1665.23077	19952.5504	3168375.91	39
4800	-692.181818	4.26197708	44	1652.27273	19894.5694	3142763.03	44
5280	-726.208333	4.10287216	48	1647.29167	19913.3895	3197116.98	48
5760	-787.218182	4.19870226	55	1564.56364	19927.3052	3154002.2	55
6240	-832.854839	4.24175481	62	1525.37097	19834.9173	3143638.93	62
6720	-879.927536	4.21714435	69	1484.04348	19822.6487	3155573.06	69
7200	-908.74359	4.47784931	78	1466.71795	19931.4247	3189310.33	78
7680	-928.360465	4.39522656	86	1457.09302	19802.6569	3195086.34	86
8160	-942.511111	4.32040441	90	1450.78889	19983.0976	3166910.67	90
8640	-933.656863	4.229011	102	1478.06863	19991.8668	3193441.74	102
9120	-924.153153	4.23194956	111	1488.9009	19988.7283	3178404.64	111
9600	-916.491379	4.2226151	116	1489.59483	19952.5657	3188077.54	116
10080	-903.096	4.16746329	125	1507.376	19741.3083	3142459.05	125
10560	-857.035971	4.13860606	139	1568.46043	19932.6636	3181306.85	138
11040	-816.986395	4.10318886	147	1604.27891	19853.8026	3156100.45	145

Trainingsdatenaufbereitung

1. Erstellung weiterer Spalten für vergangene Zeitschritte und die vorherzusagende CycleTime

Lateness (t-2)	Assembly (t-2)	Total (t-2)	CycleTime (t-2)	Consumab (t-2)	Material (t-2)	InDueTotal (t-2)	Lateness (t-1)	Assembly (t-1)	. . .

. . .	Material (t-1)	InDueTotal (t-1)	Lateness (t-0)	Assembly (t-0)	Total (t-0)	Consumab (t-0)	Material (t-0)	InDueTotal (t-0)	CycleTime (t+1)

Trainingsdatenaufbereitung

2. Füllen der Spalten für vergangene Zeitschritte durch Verschiebung

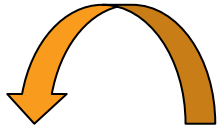
Verschiebung um 1

Verschiebung um 1

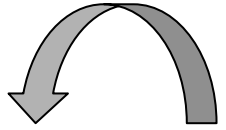
InDueTotal (t-1)	Consumab (t-1)	Material (t-1)	Lateness (t-1)	Total (t-1)	Assembly (t-1)	CycleTime (t-1)	InDueTotal (t-0)	Consumab (t-0)	Material (t-0)	Lateness (t-0)	Total (t-0)	Assembly (t-0)	CycleTime (t+1)
20	19534,8314	3051672,43	-1045,2	20	4,895794643	1362,05	20	19534,8314	3051672,43	-1045,2	20	4,895794643	1362,05
33	19910,43014	3139436,858	-762,6969697	33	4,572355469	1596,363636	33	19910,43014	3139436,858	-762,6969697	33	4,572355469	1596,363636
39	19952,5504	3168375,907	-705,4615385	39	4,295170139	1665,230769	39	19952,5504	3168375,907	-705,4615385	39	4,295170139	1665,230769
44	19894,56938	3142763,032	-692,1818182	44	4,261977083	1652,272727	44	19894,56938	3142763,032	-692,1818182	44	4,261977083	1652,272727
48	19913,38947	3197116,977	-726,2083333	48	4,102872159	1647,291667	48	19913,38947	3197116,977	-726,2083333	48	4,102872159	1647,291667
55	19927,30522	3154002,203	-787,2181818	55	4,198702257	1564,563636	55	19927,30522	3154002,203	-787,2181818	55	4,198702257	1564,563636
62	19834,9173	3143638,927	-832,8548387	62	4,241754808	1525,370968	62	19834,9173	3143638,927	-832,8548387	62	4,241754808	1525,370968
69	19822,64871	3155573,063	-879,9275362	69	4,217144345	1484,043478	69	19822,64871	3155573,063	-879,9275362	69	4,217144345	1484,043478
78	19931,42473	3189310,327	-908,7435897	78	4,477849306	1466,717949	78	19931,42473	3189310,327	-908,7435897	78	4,477849306	1466,717949
86	19802,65686	3195086,344	-928,3604651	86	4,395226562	1457,093023	86	19802,65686	3195086,344	-928,3604651	86	4,395226562	1457,093023
90	19983,09765	3166910,666	-942,5111111	90	4,320404412	1450,788889	90	19983,09765	3166910,666	-942,5111111	90	4,320404412	1450,788889
102	19991,86676	3193441,735	-933,6568627	102	4,229010995	1478,068627	102	19991,86676	3193441,735	-933,6568627	102	4,229010995	1478,068627
111	19988,72827	3178404,639	-924,1531532	111	4,231949561	1488,900901	111	19988,72827	3178404,639	-924,1531532	111	4,231949561	1488,900901
116	19952,56574	3188077,541	-916,4913793	116	4,222615104	1489,594828	116	19952,56574	3188077,541	-916,4913793	116	4,222615104	1489,594828

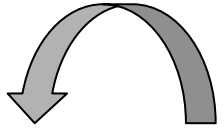
Zielspalte

Trainingsdatenaufbereitung



Weitere Verschiebungen möglich

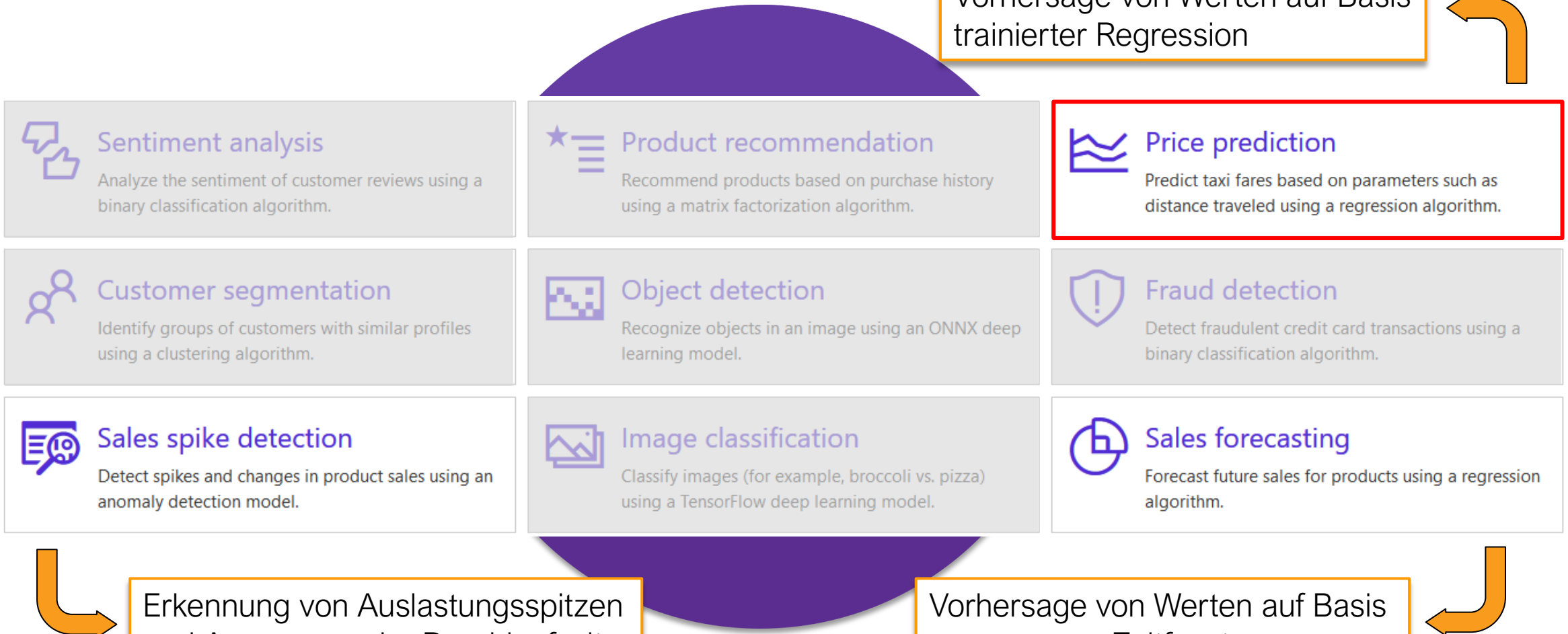




CycleTime (t-2)	InDueTotal (t-1)	Consumab (t-1)	Material (t-1)	Lateness (t-1)	Total (t-1)	Assembly (t-1)	CycleTime (t-1)	InDueTotal (t-0)	Consur
								20	19
	20	19534,8314	3051672,43	-1045,2	20	4,895794643	1362,05	33	199
1362,05	33	19910,43014	3139436,858	-762,6969697	33	4,572355469	1596,363636	39	19
1596,363636	39	19952,5504	3168375,907	-705,4615385	39	4,295170139	1665,230769	44	198
1665,230769	44	19894,56938	3142763,032	-692,1818182	44	4,261977083	1652,272727	48	199
1652,272727	48	19913,38947	3197116,977	-726,2083333	48	4,102872159	1647,291667	55	199
1647,291667	55	19927,30522	3154002,203	-787,2181818	55	4,198702257	1564,563636	62	19
1564,563636	62	19834,9173	3143638,927	-832,8548387	62	4,241754808	1525,370968	69	198
1525,370968	69	19822,64871	3155573,063	-879,9275362	69	4,217144345	1484,043478	78	199
1484,043478	78	19931,42473	3189310,327	-908,7435897	78	4,477849306	1466,717949	86	198
1466,717949	86	19802,65686	3195086,344	-928,3604651	86	4,395226562	1457,093023	90	199
1457,093023	90	19983,09765	3166910,666	-942,5111111	90	4,320404412	1450,788889	102	199
1450,788889	102	19991,86676	3193441,735	-933,6568627	102	4,229010995	1478,068627	111	199
1478,068627	111	19988,72827	3178404,639	-924,1531532	111	4,231949561	1488,900901	116	199
1488,900901	116	19952,56574	3188077,541	-916,4913793	116	4,222615104	1489,594828		
1489,594828									

Anwendung des Machine Learning Frameworks ML.NET

Vorhersage von Werten auf Basis trainierter Regression



Erkennung von Auslastungsspitzen und Anpassung der Durchlaufzeit

Vorhersage von Werten auf Basis vergangener Zeitfenster

Anwendung des Machine Learning Frameworks ML.NET

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Data Preparation → Data Loading → Model Training → Model Evaluation → Model Consumption

Korrelation	Time	Idle:Assem	Lateness	Assemblin	Idle:Assem	Idle:Drillin	TotalSetup	Idle:Drillin	InDue	OverDue	New
Time	1	-0,0402	0,703379	0,024996	0,035356	0,021281	0,059635	-0,11205	-0,08515	0,01681	-0,12644
Idle:Assemb	-0,0402	1	0,061262	-0,48545	0,538106	0,354384	-0,43953	0,263007	0,056257	0,469593	-0,00519
Lateness	0,703379	0,061262	1	-0,03799	0,146833	-0,17504	0,114578	-0,2623	-0,18399	0,058958	-0,17641
Assembling(	0,024996	-0,48545	-0,03799	1	-0,57018	-0,53203	0,899837	-0,319	-0,00026	-0,29096	-0,12207
Idle:Assemb	0,035356	0,538106	0,146833	-0,57018	1	0,395079	-0,47045	0,104472	-0,07068	0,433135	-0,04178
Idle:Drilling	0,021281	0,354384	-0,17504	-0,53203	0,395079	1	-0,65344	0,60739	0,002532	0,266047	-0,04148
TotalSetup	0,059635	-0,43953	0,114578	0,899837	-0,47045	-0,65344	1	-0,54152	-0,0339	-0,28164	-0,13718
Idle:Drilling	-0,11205	0,263007	-0,2623	-0,319	0,104472	0,60739	-0,54152	1	-0,03749	0,208881	0,067427
InDue	-0,08515	0,056257	-0,18399	-0,00026	-0,07068	0,002532	-0,0339	-0,03749	1	-0,35835	-0,09634
OverDue	0,01681	0,469593	0,058958	-0,29096	0,433135	0,266047	-0,28164	0,208881	-0,35835	1	-0,10398
New	-0,12644	-0,00519	-0,17641	-0,12207	-0,04178	-0,04148	-0,13718	0,067427	-0,09634	-0,10398	1
Product	-0,19501	-0,01035	-0,65086	-0,02337	-0,15767	0,358633	-0,29138	0,430278	0,067483	-0,02901	0,25371
AdherenceTo	0,004816	-0,44978	-0,04948	0,3	-0,47118	-0,28678	0,282538	-0,20121	0,40156	-0,95901	0,138807
Idle:Assemb	0,027617	0,294283	0,189936	-0,41527	0,392151	0,394728	-0,41095	0,240361	-0,12561	0,565954	-0,06619
Idle:Assemb	0,18355	0,155839	0,170628	-0,35596	0,382923	0,325611	-0,30856	0,179942	0,005484	0,183518	-0,15042
Idle:Drilling	-0,06644	0,278679	-0,31838	-0,48166	0,270013	0,810014	-0,6524	0,579141	0,010524	0,238829	0,019148
TotalWork	-0,17637	0,33893	-0,12814	-0,75628	0,360763	0,446174	-0,74781	0,361675	0,012982	0,188219	0,416738
Finished	-0,08051	0,317497	-0,16144	-0,16112	0,165706	0,153101	-0,19145	0,081127	0,856511	0,174916	-0,15909
OEE	-0,17746	0,338159	-0,12753	-0,75632	0,362216	0,445794	-0,74758	0,36137	0,011188	0,189213	0,415464
CuttingOper	0,020705	-0,2669	0,185736	0,446001	-0,24678	-0,49409	0,730836	-0,52156	-0,11554	-0,17054	-0,01543
Idle:Assemb	0,083171	0,297106	0,022141	-0,46512	0,46431	0,595506	-0,48574	0,332206	-0,13433	0,465875	-0,07041
Idle:Drilling	-0,13664	0,422097	-0,19194	-0,58223	0,253732	0,626509	-0,71277	0,523778	-0,08927	0,235321	0,076393

Korrelationsanalyse

Time	0,882839814	Assembling1	-0,00084644
Idle:Assembling	-0,006587485	Assembly	-0,94799926
Lateness	0,997637594	Total	0,89407951
AssemblingOpe	-0,141851475	Idle:Cutting To	0,08510948
Idle:Assembling	0,180313071	Idle:Cutting To	0,05711395
Idle:Drilling Too	0,157674007	Worker2	0,15821874
TotalSetup	-0,159253828	OverDueTotal	0,94504994
Idle:Drilling Too	0,10135359	Cutting1	-0,04896553
InDue	-0,016744137	Worker3	0,21612601
OverDue	0,061861848	Idle:Cutting To	-0,0027869
New	-0,045952598	CycleTime	1
Product	-0,67372162	Idle:Assemblir	0,04596797
AdherenceToDu	-0,137682672	Consumab	0,52701318
Idle:Assembling	0,077733549	Drilling1	-0,08699613
Idle:Assembling	0,185653024	DrillingOperat	-0,1866261
Idle:Drilling Too	0,081013811	Tardiness	0,89631063
TotalWork	0,130598494	Cutting2	0,00811704
Finished	0,004270916	Idle:Cutting To	0,00712345
OEE	0,12990943	Idle:Assemblir	0,2373574
CuttingOperato	-0,060056266	Material	0,66226909
Idle:Assembling	0,236712828	InDueTotal	0,88801836
Idle:Drilling Too	0,195816212	Open	-0,0638786
Assembling2	0,175105947	Worker1	-0,04789451

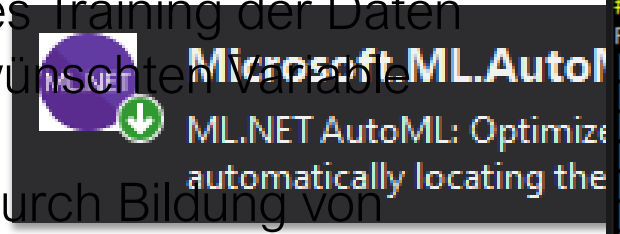
Herausfiltern der Features

CycleTime (t-2)	InDueTotal (t-1)	Consumab (t-1)	Material (t-1)	Lateness (t-1)	Total (t-1)	Assembly (t-1)	CycleTime (t-1)
	20	19534,8314	3051672,43	-1045,2	20	4,895794643	1362,05
1362,05	33	19910,43014	3139436,858	-762,6969697	33	4,572355469	1596,363636
1596,363636	39	19952,5504	3168375,907	-705,4615385	39	4,295170139	1665,230769
1665,230769	44	19894,56938	3142763,032	-692,1818182	44	4,261977083	1652,272727
1652,272727	48	19913,38947	3197116,977	-726,2083333	48	4,102872159	1647,291667
1647,291667	55	19927,30522	3154002,203	-787,2181818	55	4,198702257	1564,563636
1564,563636	62	19834,9173	3143638,927	-832,8548387	62	4,241754808	1525,370968
1525,370968	69	19822,64871	3155573,063	-879,9275362	69	4,217144345	1484,043478
1484,043478	78	19931,42473	3189310,327	-908,7435897	78	4,477849306	1466,717949
1466,717949	86	19802,65686	3195086,344	-928,3604651	86	4,395226562	1457,093023
1457,093023	90	19983,09765	3166910,666	-942,5111111	90	4,320404412	1450,788889
1450,788889	102	19991,86676	3193441,735	-933,6568627	102	4,229010995	1478,068627
1478,068627	111	19988,72827	3178404,639	-924,1531532	111	4,231949561	1488,900901
1488,900901	116	19952,56574	3188077,541	-916,4913793	116	4,222615104	1489,594828
1489,594828							

Trainingsdatenaufbereitung

- Automatisches Training der Daten nach der gewünschten Variable
  → CycleTime
- Evaluierung durch Bildung von Testdatensets
- Ausgabe des für die gegebenen Daten besten Trainers

→ Speicherung des Modells

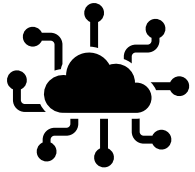



```
=============== Training the model ===============
###################################################
Running AutoML regression experiment for 300 seconds...
|     Trainer                          RSquared Absolute-loss Squared-loss RMS-loss  Duration
|1    SdcaRegression                     0,9854         14,73       647,74    24,45       3,3
|2    LightGbmRegression                 0,9908         10,06       408,83    19,36       2,8
|3    FastTreeRegression                 0,9913          9,30       390,13    18,12       7,3
|4    FastTreeTweedieRegression          0,9917          9,81       368,29    18,23       7,7
|5    FastForestRegression               0,9842         15,14       697,50    25,50       7,4
|6    LbfgsPoissonRegression             0,9873         14,02       564,71    22,90       1,4
|7    OnlineGradientDescentRegression    0,6469         96,76     14932,19   121,69       0,9
|8    OlsRegression                      0,9955          6,30       201,17    13,49       1,0
|9    FastTreeRegression               -26,9440       1079,45   1195622,38  1093,34       1,3
|10   FastTreeTweedieRegression        -50,6946       1472,71   2211510,38  1487,01       2,1
|11   OlsRegression                      0,9635         27,77      1597,30    39,50       0,9
|12   FastTreeRegression                 0,8382         79,78      6964,27    83,39       4,3
|13   FastTreeTweedieRegression        -52,7657       1502,21   2300106,26  1516,50       1,2
|14   OlsRegression                      0,9955          6,30       201,17    13,49       0,9
|15   FastTreeRegression                 0,9557         36,25      1926,84    43,64       8,7
|16   FastTreeTweedieRegression        -52,8925       1504,00   2305530,53  1518,29       1,2
|17   OlsRegression                      0,1631        146,79     36124,99   189,86       0,9
|18   FastTreeRegression                -9,2789        656,54    439776,02   663,11      43,8
|19   FastTreeTweedieRegression        -52,8293       1503,11   2302824,67  1517,40       1,4
|20   OlsRegression                      0,9635         27,77      1597,30    39,50       1,4
```

Data Preparation → Data Loading → Model Training → Model Evaluation → **Model Consumption**

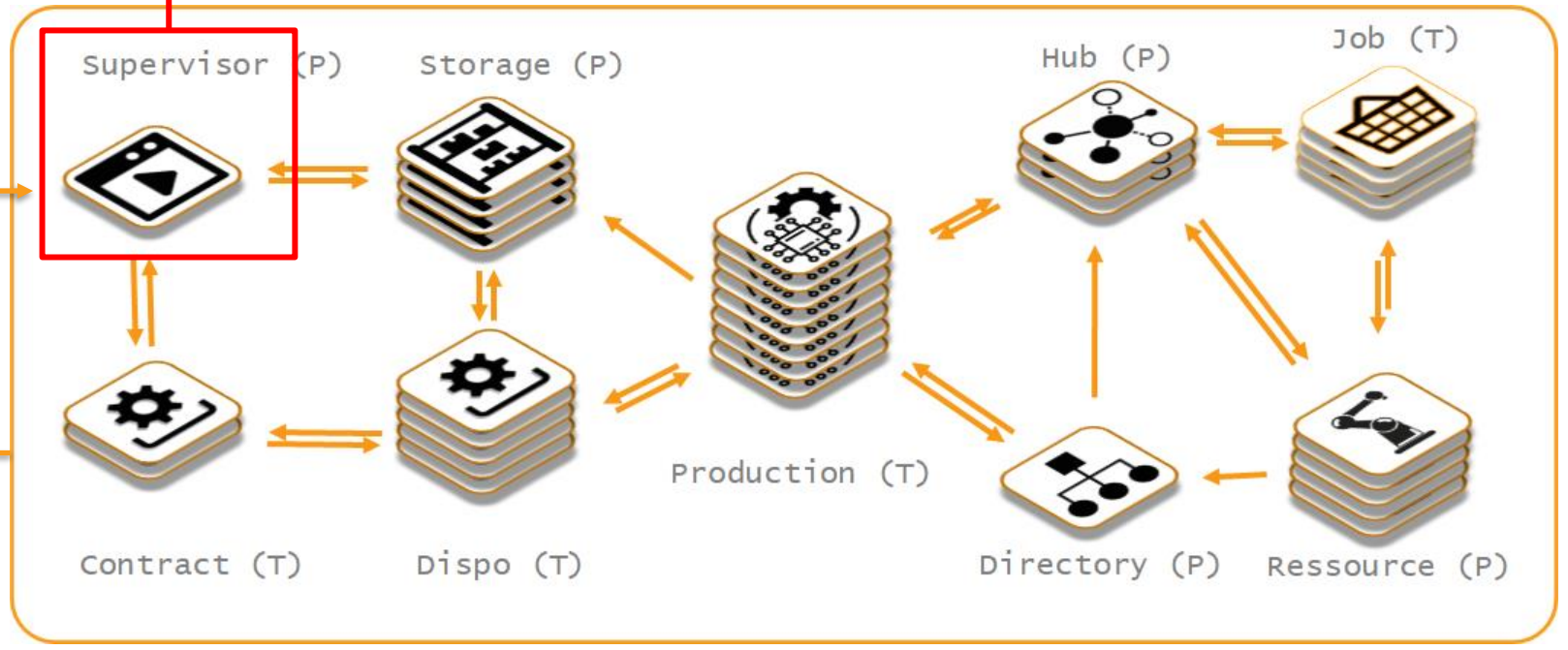
- Triggert Vorhersage der Durchlaufzeit
- Löst Aufträge aus

Collector



Sendet Kpis

Sammelt Kpis

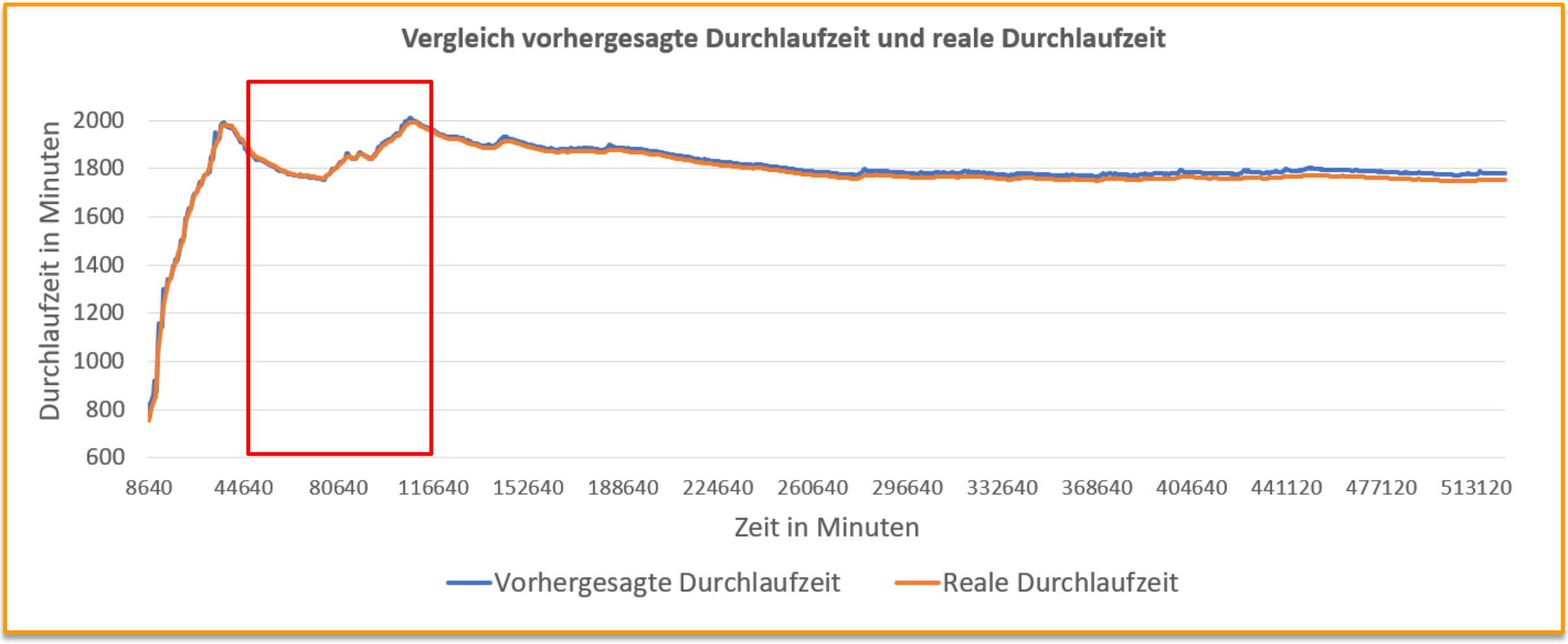


Anwendung des Machine Learning Frameworks ML.NET

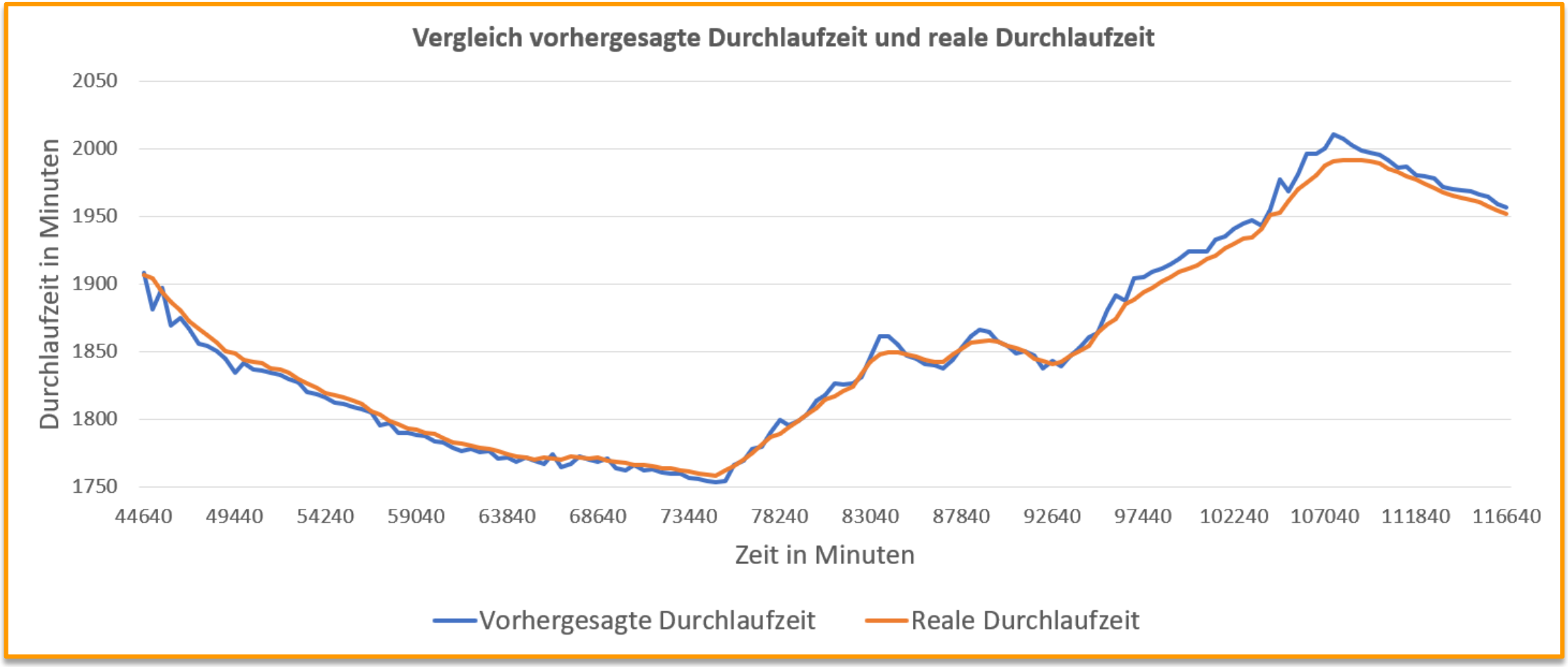

```
public long PredictThroughput(List<SimulationKpis> valuesForPrediction)
{
    //Transform collected Kpis to required shape
    var kpisForPredict = getReshapedKpisForPrediction(valuesForPrediction);

    // Load trained Model
    ITransformer trainedModel = mlContext.Model.Load(ModelPath, out var modelInputSchema);

    // Create prediction engine related to the loaded trained model.
    var predEngine = mlContext.Model.CreatePredictionEngine<SimulationKpisReshaped, CycleTimePrediction>(trainedModel);

    // Make prediction based on input Kpis
    var resultPrediction = predEngine.Predict(kpisForPredict);

    return (long)Math.Round(resultPrediction.CycleTime, 0);
}
```

Darlegung der Ergebnisse

Darlegung der Ergebnisse

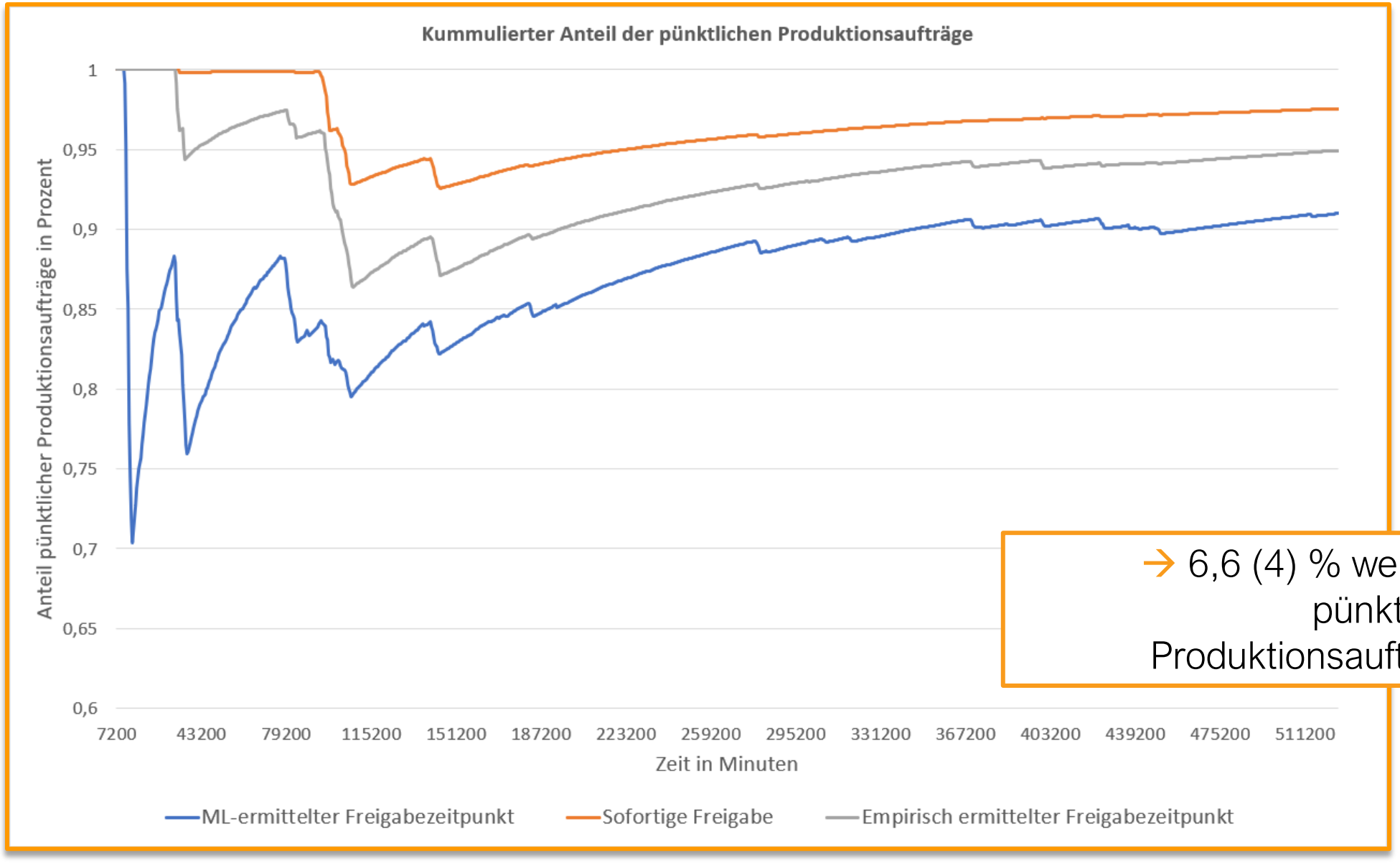


Darlegung der Ergebnisse



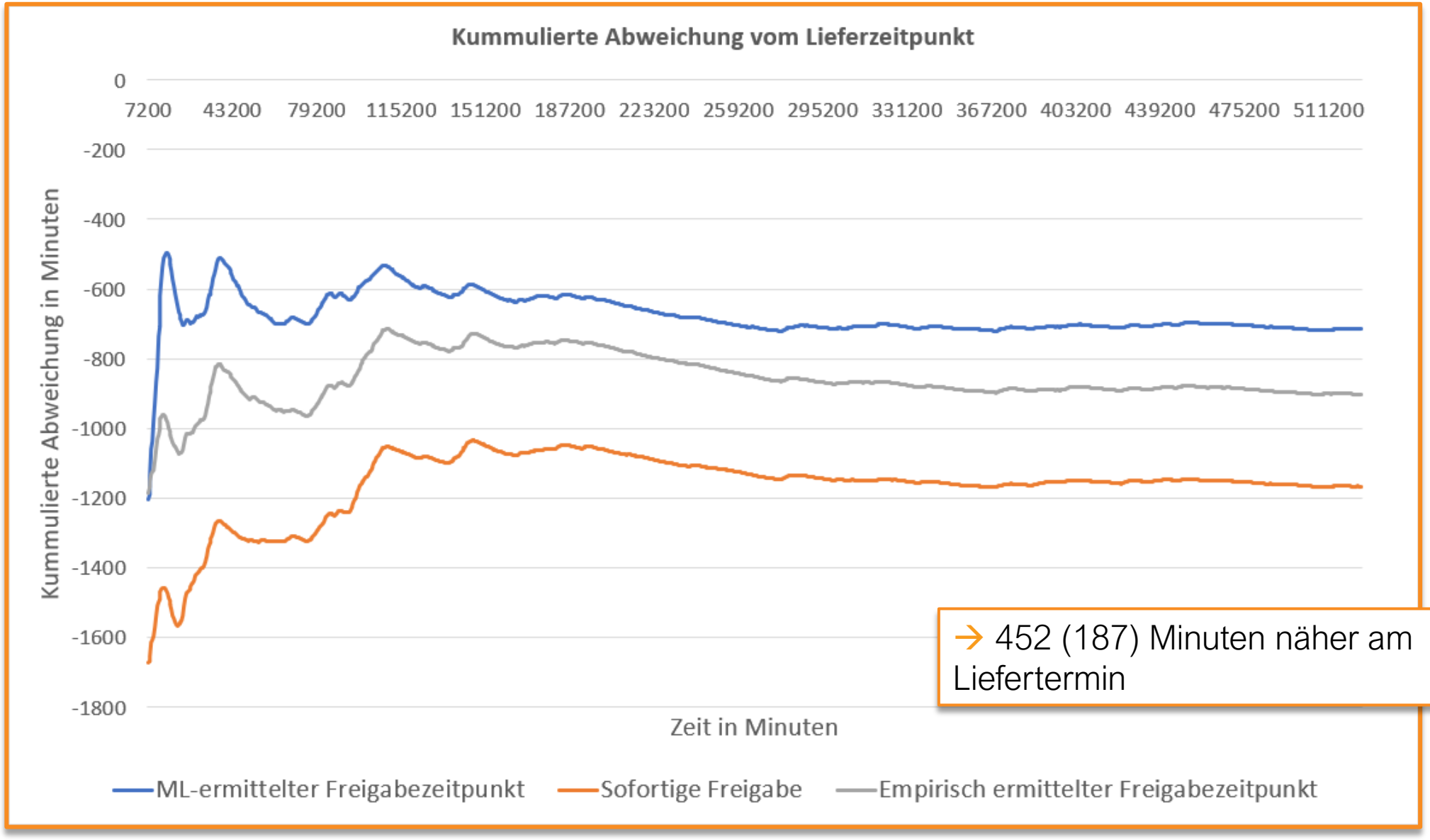
→ Durchschnittliche Abweichung: 0,92%

Darlegung der Ergebnisse



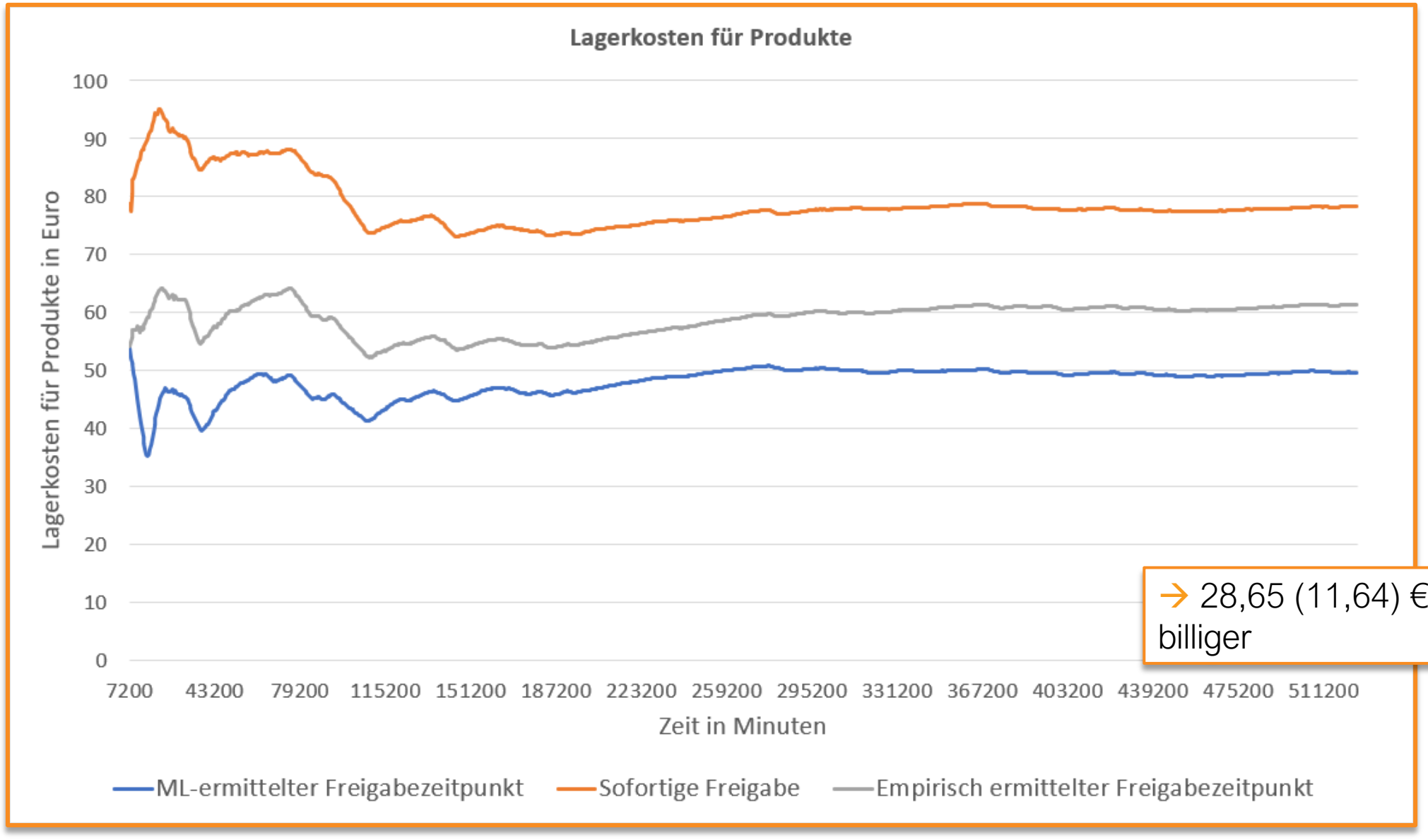
→ 6,6 (4) % weniger pünktliche Produktionsaufträge

Darlegung der Ergebnisse



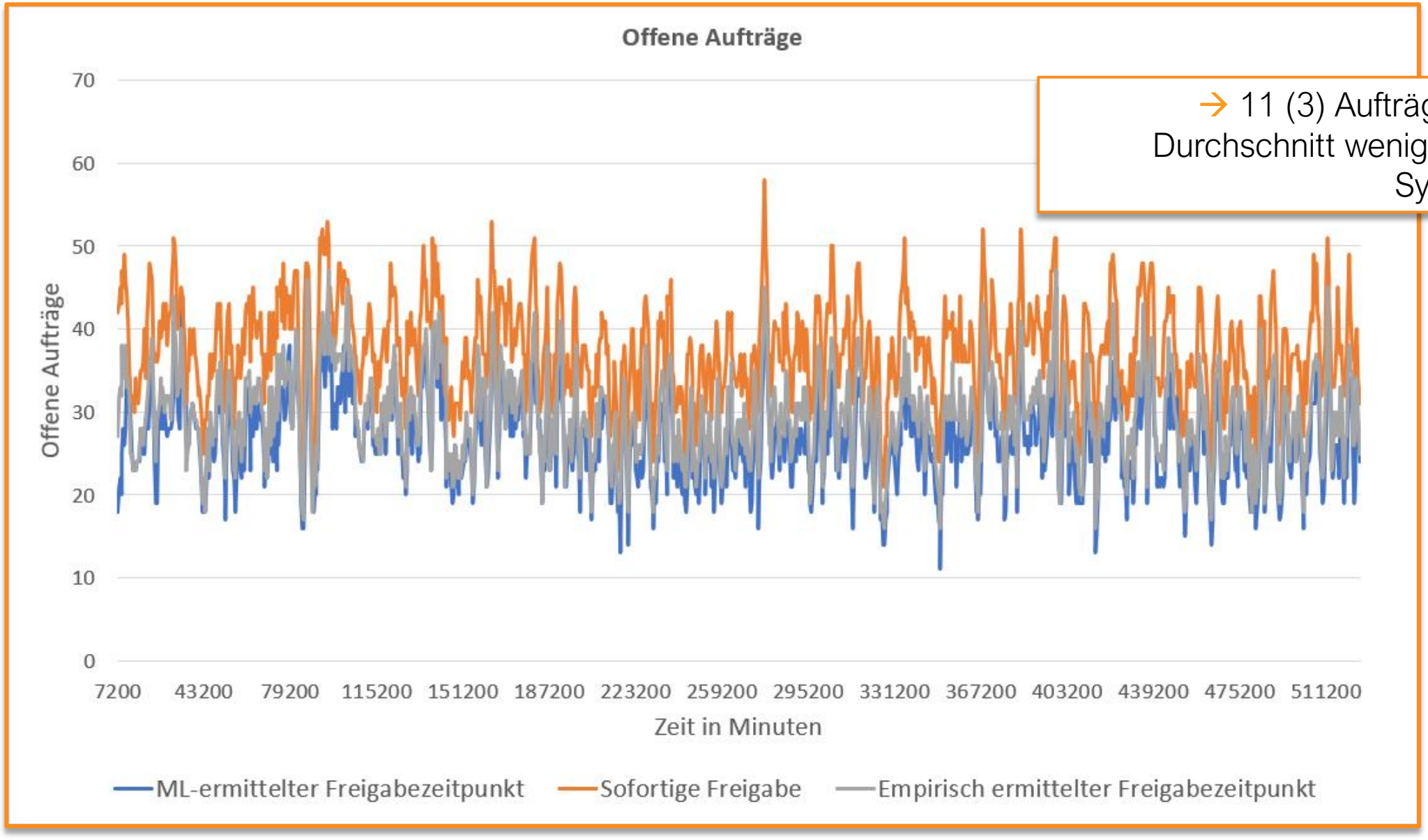
→ 452 (187) Minuten näher am Liefertermin

Darlegung der Ergebnisse



→ 28,65 (11,64) € billiger

Darlegung der Ergebnisse



→ 11 (3) Aufträge im Durchschnitt weniger im System

Zusammenfassung und Ausblick

Ergebnis des Forschungs- und Entwicklungsseminars

- Teilweise bessere Ergebnisse im Vergleich zur Ausgangssituation
- Erstes Mal Machine Learning in der SSOP
- Aufbau soliden Grundlagenwissens zu Machine Learning

Ausblick

- Modell bei abweichenden Simulationsparametern liefert unzureichende Vorhersagen
  → Verbesserung der Trainingsdaten für genauere Vorhersagen variabler Parameter
- Gleiche Durchlaufzeit wird für alle Produkte gesetzt
  → Vorhersage Abhängigkeit der Eigenschaften des Produktionsauftrags
- Testen weiterer Anwendungsfälle / Methoden
  - Schätzung von Losgrößen und Wartezeiten
  - Anomaly Detection
  - Deep Learning @ SSOP mit Keras

Vielen Dank für Ihre Aufmerksamkeit!

..und Danke an unsere Betreuer!