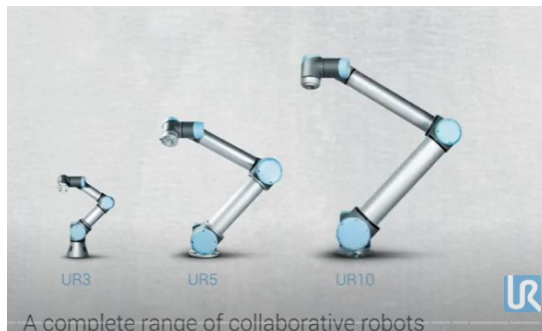


UR3 CobotOps Automation Analysis

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28 Mar 2025

Introduction and Dataset

- **Robotics/automation:** Working with robotics and automation creates workflow efficiencies.
 - To get the most out of your robotic system and optimise planning, you must understand its operation and mitigate for issues.
- **Dataset:** UR3 CobotOps Dataset - time-series data from the UR3 cobot
 - offers insights into operational parameters and faults.
 - Currents, speeds across joints (J0-J5), gripper/tool current, operation cycle count, protective stops, and grip losses
- **Objective:** Explore data and investigate feasibility of error prediction
- **Pre-processing:** All features continuous except cycle, grip lost and protective stop
 - Only continuous features had missing data - filled missing data with data from previous row
 - Grip lost changed False to 0 and True to 1
 - Extracted timestamp, date and time data in correct format

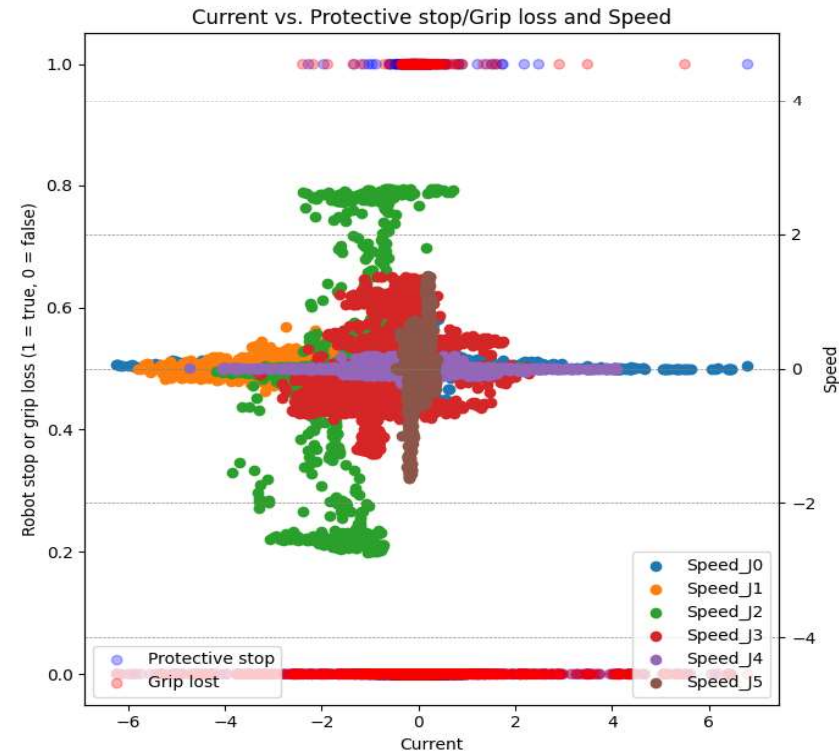
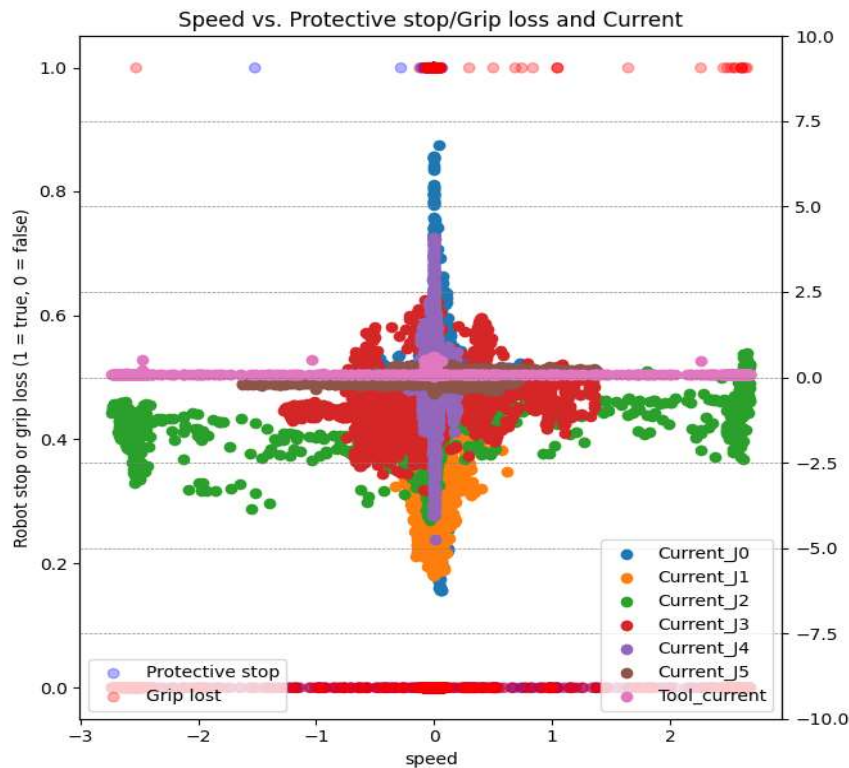


- Dataset Reference: M. Tyrovolas, K. Aliev, D. Antonelli, and C. Stylios. "UR3 CobotOps," UCI Machine Learning Repository, 2024. <https://doi.org/10.24432/C5J891>
- Video reference: [Robotics applications by Universal Robots - Easy Automation with Collaborative Robots \[2020 \]](#)
- [Collaboration at all levels – experience Universal Robots in 21 applications at Hanover Fair 2017](#)

EDA: Current and speed

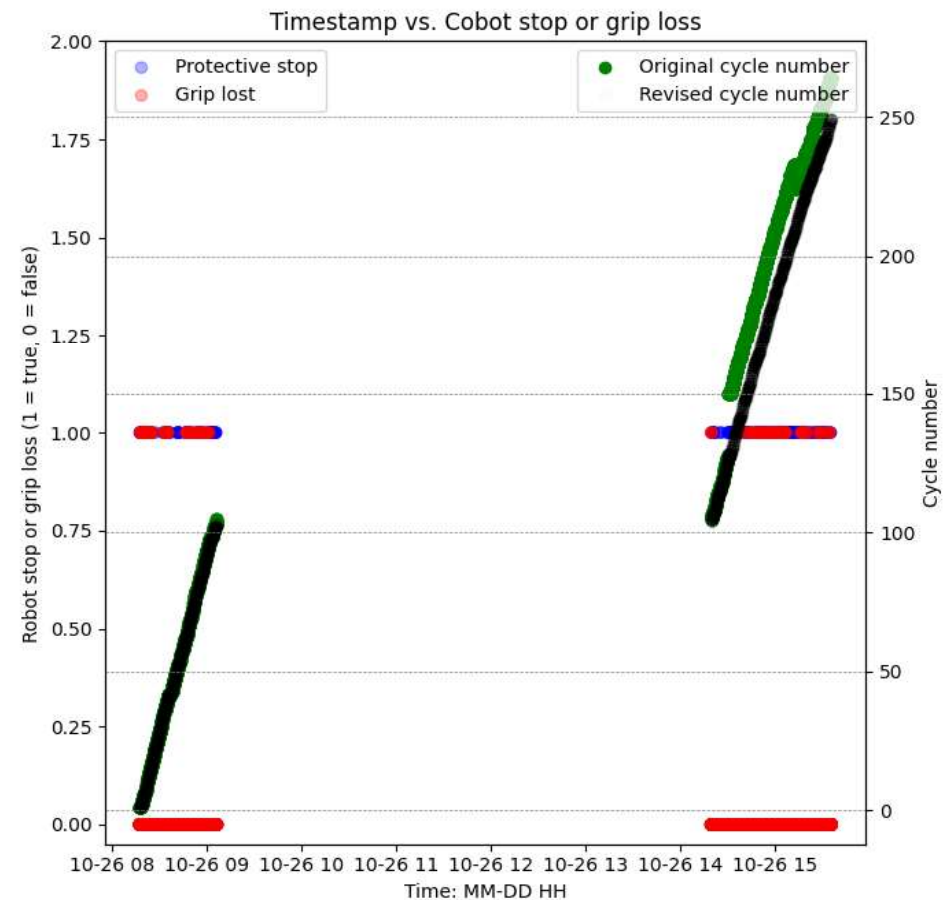
- Current and speed centralised on zero with negative and positive indicating or controlling cobot arm movement in different directions
- Each arm J0-J5 and the tool/gripper has it's own pattern
- Grip loss or protective stop faults happen less in negative range

*EDA:Exploratory data analysis



EDA: Cycles and faults over time

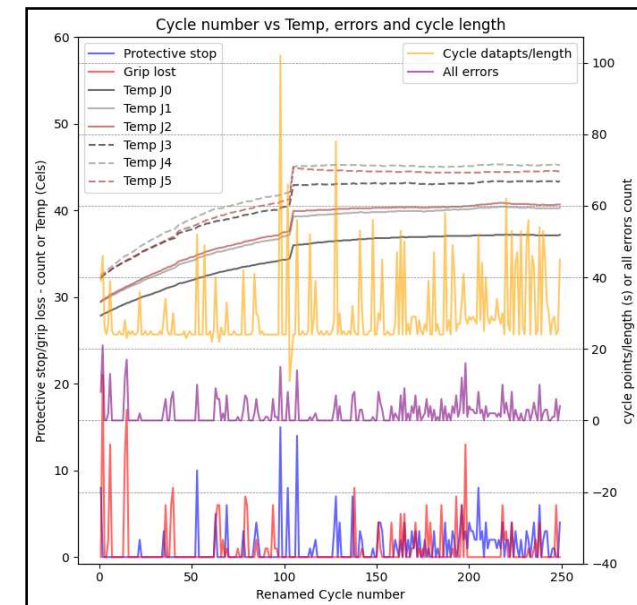
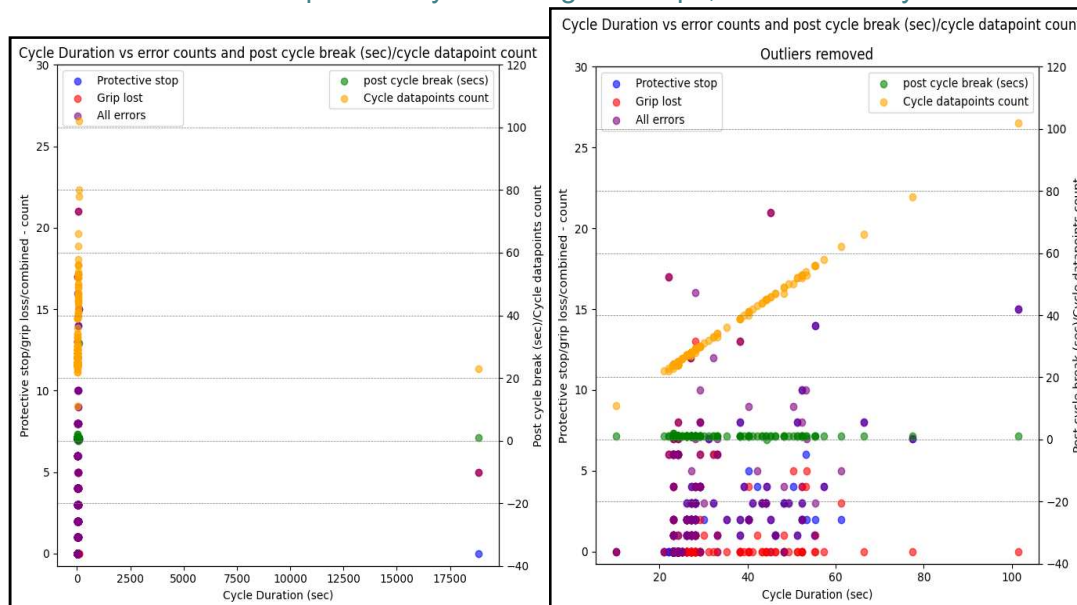
- Major stop in operations from approx 09:00 until 14:00
 - Cycles out of sync of expected after this
 - Could be planned or human intervention and re-planning due to robot issues
- Generated new features
 - New cycle such that cycles are continuous with timestamp
 - Likely errors that cycles were skipped/repeated
 - Cycle timepoint sec
 - Compare cycle stages as cycles are varying durations



EDA: Cycle Summary – Temperature, duration, post cycle & error behaviour

- Generated summary table for each cycle
 - 2 outlier data rows removed
- Break post cycle consistently approx 1sec
 - Automation controlled unless human interference (deleted outlier)
- Expected might be a relationship of higher error counts and longer cycle duration - linear relationship is only cycle datapoints count
 - Different activities each cycle?
 - or
 - Robot automatically devising next best move, making cycles length inconsistent – is timing an issue for the cycles/process?
- Temperature increase over course of day with uptick at cycle 104 where long break occurred
 - Protective stops most cycles at higher temps, later in the day

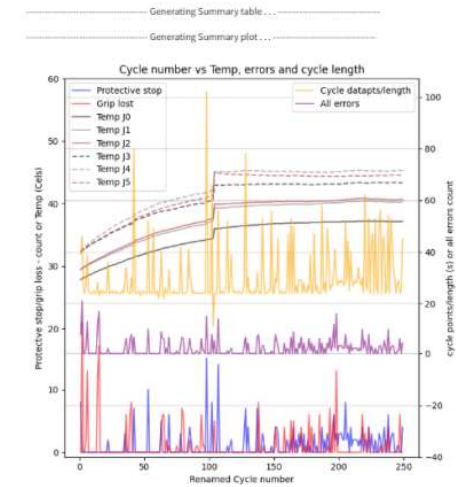
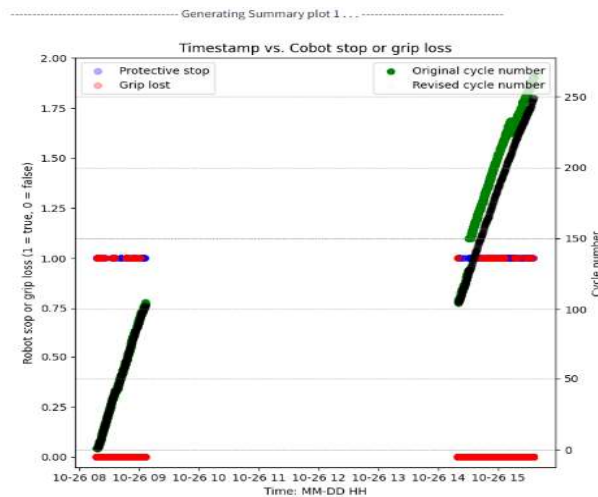
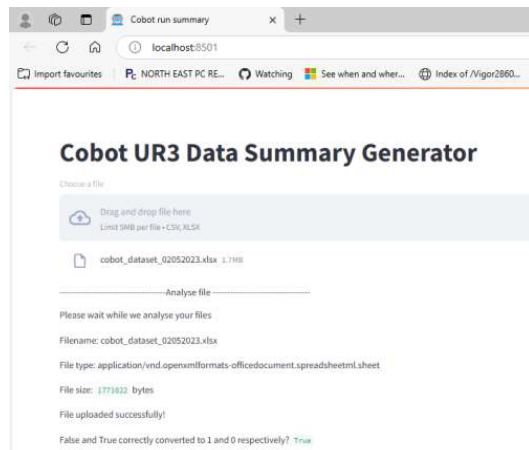
cyc_rename	104	98	42	128
cyc_original	105	99	42	150
grip_lost	5	0	0	0
protective_stop	0.0	15.0	7.0	7.0
cyc_datapts	23	102	80	78
duration sec	10835.24	101.482	88.459	77.394
break post c sec	1.004	1.007	31.15	1.006



Streamlit (video): Updated 02Apr Data Summary Generator Application

- [DevAcProj_CobotOps/Cobot_data_summ_app_vid.mp4 at main · Ddbol/DevAcProj_CobotOps](#)

Streamlit (screenshots): Data Summary Generator Application



These are the cycles where grip loss(es) occurred:

```
[
  0 : "3"
  1 : "5"
  2 : "6"
  3 : "14"
  4 : "15"
  5 : "36"
  6 : "39"
  7 : "40"
  8 : "63"
  9 : "64"
  10 : "65"
  11 : "67"
  12 : "69"
  13 : "75"
  14 : "79"
]
```

These are the cycles where grip loss(es) occurred:

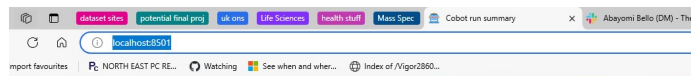
```
[ ... ]
```

These are the cycles where protective stop(s) occurred:

```
[
  0 : "1"
  1 : "22"
  2 : "35"
  3 : "42"
  4 : "53"
  5 : "63"
  6 : "69"
  7 : "78"
  8 : "84"
  9 : "85"
  10 : "86"
  11 : "98"
  12 : "102"
  13 : "107"
  14 : "114"
  15 : "116"
]
```

	cyc_rename	cyc_original	grip_lost	protective_stop	cyc_end	cyc_start	duration	cyc_datapoints	temp_j0	temp_j1	temp_j2	temp_j3	temp_j4	temp_j5	all_errors	break_prot_cyc	duration_sec	break_prot_c_sec	
0	1	2	0	0	8.0000	2022-10-26 08:18:00	2022-10-26 08:17:21	a few seconds	39	27.8750	29.4375	29.5000	32.2500	32.3750	32.1250	0.0000	a few seconds	38.2240	1.0150
1	2	2	21	0	0.0000	2022-10-26 08:18:46	2022-10-26 08:18:01	a minute	46	28.0000	29.6250	29.6875	32.4375	32.6875	32.4375	21.0000	a few seconds	45.2240	1.0070
2	3	3	0	0	0.0000	2022-10-26 08:19:12	2022-10-26 08:18:47	a few seconds	26	26.1250	29.6875	29.8125	32.6250	32.8750	32.6250	0.0000	a few seconds	25.1180	1.0050
3	4	4	0	0	0.0000	2022-10-26 08:19:36	2022-10-26 08:18:43	a few seconds	24	26.1875	29.8125	29.9375	32.8125	33.0625	32.7500	0.0000	a few seconds	23.1200	1.0060
4	5	5	2	0	0.0000	2022-10-26 08:20:03	2022-10-26 08:19:37	a few seconds	27	26.3125	29.9375	30.0625	32.9375	33.2500	32.8750	2.0000	a few seconds	26.1050	1.0020
5	6	6	13	0	0.0000	2022-10-26 08:20:42	2022-10-26 08:20:04	a few seconds	39	28.4375	30.0625	30.2500	33.0625	33.3750	33.0625	13.0000	a few seconds	38.1990	1.0060
6	7	7	0	0	0.0000	2022-10-26 08:21:08	2022-10-26 08:20:43	a few seconds	25	28.5000	30.1875	30.3750	33.2500	33.5625	33.2500	0.0000	a few seconds	24.1460	1.0060
7	8	8	0	0	0.0000	2022-10-26 08:21:32	2022-10-26 08:21:09	a few seconds	24	26.6250	30.2613	30.4375	33.3750	33.7500	33.3750	0.0000	a few seconds	23.1060	1.0050
8	9	9	0	0	0.0000	2022-10-26 08:21:56	2022-10-26 08:21:33	a few seconds	24	26.6875	30.3750	30.5625	33.5000	33.9063	33.5000	0.0000	a few seconds	23.1030	1.0020
9	10	10	0	0	0.0000	2022-10-26 08:22:20	2022-10-26 08:21:57	a few seconds	24	28.8125	30.5000	30.6875	33.6250	34.0625	33.6250	0.0000	a few seconds	23.1200	1.0050
10	11	11	0	0	0.0000	2022-10-26 08:22:45	2022-10-26 08:22:21	a few seconds	25	28.9375	30.6250	30.8125	33.7500	34.2500	33.7500	0.0000	a few seconds	24.1130	1.0030
11	12	12	0	0	0.0000	2022-10-26 08:23:09	2022-10-26 08:22:46	a few seconds	24	29.0000	30.7500	30.8750	33.8750	34.4063	33.8750	0.0000	a few seconds	23.1540	1.0030
12	13	13	0	0	0.0000	2022-10-26 08:23:32	2022-10-26 08:23:10	a few seconds	24	29.1250	30.8125	31.0000	34.0000	34.5625	34.0000	0.0000	a few seconds	23.0860	2.0020
13	14	14	12	0	0.0000	2022-10-26 08:24:02	2022-10-26 08:23:35	a few seconds	28	29.1875	30.9375	31.1250	34.1250	34.7500	34.1250	12.0000	a few seconds	27.0750	1.0030
14	15	15	17	0	0.0000	2022-10-26 08:24:25	2022-10-26 08:24:03	a few seconds	23	29.3125	31.0625	31.2500	34.1875	34.8125	34.2500	17.0000	a few seconds	22.1080	1.0050
15	16	16	0	0	0.0000	2022-10-26 08:24:51	2022-10-26 08:24:26	a few seconds	25	29.3750	31.1250	31.3125	34.3125	34.9375	34.3750	0.0000	a few seconds	24.1210	1.0140
16	17	17	0	0	0.0000	2022-10-26 08:25:15	2022-10-26 08:24:52	a few seconds	24	29.4375	31.2500	31.4375	34.3750	35.0625	34.5000	0.0000	a few seconds	23.1520	1.0020
17	18	18	0	0	0.0000	2022-10-26 08:25:40	2022-10-26 08:25:16	a few seconds	25	29.5625	31.3125	31.5000	34.5000	35.1875	34.6250	0.0000	a few seconds	24.0120	1.0050
18	19	19	0	0	0.0000	2022-10-26 08:26:04	2022-10-26 08:25:41	a few seconds	24	29.6250	31.4375	31.6250	34.6250	35.3125	34.7500	0.0000	a few seconds	23.1460	1.0040

Streamlit (screenshots): Updated 02Apr Data Summary Generator Application



Cobot UR3 Data Summary Generator

Choose a file

Drag and drop file here
or
Click to select a file

File name: `cobot_dataset_02052023.xlsx`

File type: `application/vnd.openxmlformats-officedocument.spreadsheetml.sheet`

File size: `1775322` bytes

File uploaded successfully!

Analyzing file...

Please wait while we analyse your file

False and True correctly converted to 0 and 1 respectively? ☒ True

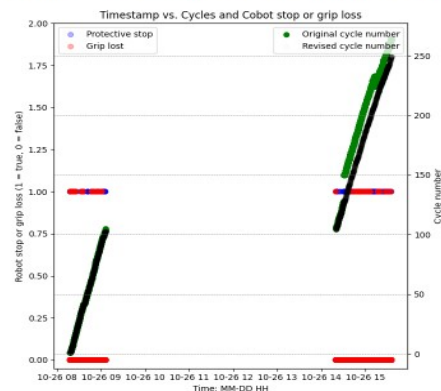
Generating Summary table...

Summary Table

cycle_number	cycle_start	cycle_end	protective_stop	grip_loss	cycle_start	cycle_end	temp_01	temp_02	temp_03	temp_04	temp_05	temp_06	temp_07	temp_08	temp_09	temp_10	temp_11	temp_12	temp_13	temp_14	temp_15	temp_16	temp_17	temp_18	temp_19	temp_20	temp_21	temp_22	temp_23	temp_24	temp_25	temp_26	temp_27	temp_28	temp_29	temp_30	temp_31	temp_32	temp_33	temp_34	temp_35	temp_36	temp_37	temp_38	temp_39	temp_40	temp_41	temp_42	temp_43	temp_44	temp_45	temp_46	temp_47	temp_48	temp_49	temp_50	temp_51	temp_52	temp_53	temp_54	temp_55	temp_56	temp_57	temp_58	temp_59	temp_60	temp_61	temp_62	temp_63	temp_64	temp_65	temp_66	temp_67	temp_68	temp_69	temp_70	temp_71	temp_72	temp_73	temp_74	temp_75	temp_76	temp_77	temp_78	temp_79	temp_80	temp_81	temp_82	temp_83	temp_84	temp_85	temp_86	temp_87	temp_88	temp_89	temp_90	temp_91	temp_92	temp_93	temp_94	temp_95	temp_96	temp_97	temp_98	temp_99	temp_100	temp_101	temp_102	temp_103	temp_104	temp_105	temp_106	temp_107	temp_108	temp_109	temp_110	temp_111	temp_112	temp_113	temp_114	temp_115	temp_116	temp_117	temp_118	temp_119	temp_120	temp_121	temp_122	temp_123	temp_124	temp_125	temp_126	temp_127	temp_128	temp_129	temp_130	temp_131	temp_132	temp_133	temp_134	temp_135	temp_136	temp_137	temp_138	temp_139	temp_140	temp_141	temp_142	temp_143	temp_144	temp_145	temp_146	temp_147	temp_148	temp_149	temp_150	temp_151	temp_152	temp_153	temp_154	temp_155	temp_156	temp_157	temp_158	temp_159	temp_160	temp_161	temp_162	temp_163	temp_164	temp_165	temp_166	temp_167	temp_168	temp_169	temp_170	temp_171	temp_172	temp_173	temp_174	temp_175	temp_176	temp_177	temp_178	temp_179	temp_180	temp_181	temp_182	temp_183	temp_184	temp_185	temp_186	temp_187	temp_188	temp_189	temp_190	temp_191	temp_192	temp_193	temp_194	temp_195	temp_196	temp_197	temp_198	temp_199	temp_200	temp_201	temp_202	temp_203	temp_204	temp_205	temp_206	temp_207	temp_208	temp_209	temp_210	temp_211	temp_212	temp_213	temp_214	temp_215	temp_216	temp_217	temp_218	temp_219	temp_220	temp_221	temp_222	temp_223	temp_224	temp_225	temp_226	temp_227	temp_228	temp_229	temp_230	temp_231	temp_232	temp_233	temp_234	temp_235	temp_236	temp_237	temp_238	temp_239	temp_240	temp_241	temp_242	temp_243	temp_244	temp_245	temp_246	temp_247	temp_248	temp_249	temp_250	temp_251	temp_252	temp_253	temp_254	temp_255	temp_256	temp_257	temp_258	temp_259	temp_260	temp_261	temp_262	temp_263	temp_264	temp_265	temp_266	temp_267	temp_268	temp_269	temp_270	temp_271	temp_272	temp_273	temp_274	temp_275	temp_276	temp_277	temp_278	temp_279	temp_280	temp_281	temp_282	temp_283	temp_284	temp_285	temp_286	temp_287	temp_288	temp_289	temp_290	temp_291	temp_292	temp_293	temp_294	temp_295	temp_296	temp_297	temp_298	temp_299	temp_300	temp_301	temp_302	temp_303	temp_304	temp_305	temp_306	temp_307	temp_308	temp_309	temp_310	temp_311	temp_312	temp_313	temp_314	temp_315	temp_316	temp_317	temp_318	temp_319	temp_320	temp_321	temp_322	temp_323	temp_324	temp_325	temp_326	temp_327	temp_328	temp_329	temp_330	temp_331	temp_332	temp_333	temp_334	temp_335	temp_336	temp_337	temp_338	temp_339	temp_340	temp_341	temp_342	temp_343	temp_344	temp_345	temp_346	temp_347	temp_348	temp_349	temp_350	temp_351	temp_352	temp_353	temp_354	temp_355	temp_356	temp_357	temp_358	temp_359	temp_360	temp_361	temp_362	temp_363	temp_364	temp_365	temp_366	temp_367	temp_368	temp_369	temp_370	temp_371	temp_372	temp_373	temp_374	temp_375	temp_376	temp_377	temp_378	temp_379	temp_380	temp_381	temp_382	temp_383	temp_384	temp_385	temp_386	temp_387	temp_388	temp_389	temp_390	temp_391	temp_392	temp_393	temp_394	temp_395	temp_396	temp_397	temp_398	temp_399	temp_400	temp_401	temp_402	temp_403	temp_404	temp_405	temp_406	temp_407	temp_408	temp_409	temp_410	temp_411	temp_412	temp_413	temp_414	temp_415	temp_416	temp_417	temp_418	temp_419	temp_420	temp_421	temp_422	temp_423	temp_424	temp_425	temp_426	temp_427	temp_428	temp_429	temp_430	temp_431	temp_432	temp_433	temp_434	temp_435	temp_436	temp_437	temp_438	temp_439	temp_440	temp_441	temp_442	temp_443	temp_444	temp_445	temp_446	temp_447	temp_448	temp_449	temp_450	temp_451	temp_452	temp_453	temp_454	temp_455	temp_456	temp_457	temp_458	temp_459	temp_460	temp_461	temp_462	temp_463	temp_464	temp_465	temp_466	temp_467	temp_468	temp_469	temp_470	temp_471	temp_472	temp_473	temp_474	temp_475	temp_476	temp_477	temp_478	temp_479	temp_480	temp_481	temp_482	temp_483	temp_484	temp_485	temp_486	temp_487	temp_488	temp_489	temp_490	temp_491	temp_492	temp_493	temp_494	temp_495	temp_496	temp_497	temp_498	temp_499	temp_500	temp_501	temp_502	temp_503	temp_504	temp_505	temp_506	temp_507	temp_508	temp_509	temp_510	temp_511	temp_512	temp_513	temp_514	temp_515	temp_516	temp_517	temp_518	temp_519	temp_520	temp_521	temp_522	temp_523	temp_524	temp_525	temp_526	temp_527	temp_528	temp_529	temp_530	temp_531	temp_532	temp_533	temp_534	temp_535	temp_536	temp_537	temp_538	temp_539	temp_540	temp_541	temp_542	temp_543	temp_544	temp_545	temp_546	temp_547	temp_548	temp_549	temp_550	temp_551	temp_552	temp_553	temp_554	temp_555	temp_556	temp_557	temp_558	temp_559	temp_560	temp_561	temp_562	temp_563	temp_564	temp_565	temp_566	temp_567	temp_568	temp_569	temp_570	temp_571	temp_572	temp_573	temp_574	temp_575	temp_576	temp_577	temp_578	temp_579	temp_580	temp_581	temp_582	temp_583	temp_584	temp_585	temp_586	temp_587	temp_588	temp_589	temp_590	temp_591	temp_592	temp_593	temp_594	temp_595	temp_596	temp_597	temp_598	temp_599	temp_600	temp_601	temp_602	temp_603	temp_604	temp_605	temp_606	temp_607	temp_608	temp_609	temp_610	temp_611	temp_612	temp_613	temp_614	temp_615	temp_616	temp_617	temp_618	temp_619	temp_620	temp_621	temp_622	temp_623	temp_624	temp_625	temp_626	temp_627	temp_628	temp_629	temp_630	temp_631	temp_632	temp_633	temp_634	temp_635	temp_636	temp_637	temp_638	temp_639	temp_640	temp_641	temp_642	temp_643	temp_644	temp_645	temp_646	temp_647	temp_648	temp_649	temp_650	temp_651	temp_652	temp_653	temp_654	temp_655	temp_656	temp_657	temp_658	temp_659	temp_660	temp_661	temp_662	temp_663	temp_664	temp_665	temp_666	temp_667	temp_668	temp_669	temp_670	temp_671	temp_672	temp_673	temp_674	temp_675	temp_676	temp_677	temp_678	temp_679	temp_680	temp_681	temp_682	temp_683	temp_684	temp_685	temp_686	temp_687	temp_688	temp_689	temp_690	temp_691	temp_692	temp_693	temp_694	temp_695	temp_696	temp_697	temp_698	temp_699	temp_700	temp_701	temp_702	temp_703	temp_704	temp_705	temp_706	temp_707	temp_708	temp_709	temp_710	temp_711	temp_712	temp_713	temp_714	temp_715	temp_716	temp_717	temp_718	temp_719	temp_720	temp_721	temp_722	temp_723	temp_724	temp_725	temp_726	temp_727	temp_728	temp_729	temp_730	temp_731	temp_732	temp_733	temp_734	temp_735	temp_736	temp_737	temp_738	temp_739	temp_740	temp_741	temp_742	temp_743	temp_744	temp_745	temp_746	temp_747	temp_748	temp_749	temp_750	temp_751	temp_752	temp_753	temp_754	temp_755	temp_756	temp_757	temp_758	temp_759	temp_760	temp_761	temp_762	temp_763	temp_764	temp_765	temp_766	temp_767	temp_768	temp_769	temp_770	temp_771	temp_772	temp_773	temp_774	temp_775	temp_776	temp_777	temp_778	temp_779	temp_780	temp_781	temp_782	temp_783	temp_784	temp_785	temp_786	temp_787	temp_788	temp_789	temp_790	temp_791	temp_792	temp_793	temp_794	temp_795	temp_796	temp_797	temp_798	temp_799	temp_800	temp_801	temp_802	temp_803	temp_804	temp_805	temp_806	temp_807	temp_808	temp_809	temp_810	temp_811	temp_812	temp_813	temp_814	temp_815	temp_816	temp_817	temp_818	temp_819	temp_820	temp_821	temp_822	temp_823	temp_824	temp_825	temp_826	temp_827	temp_828	temp_829	temp_830	temp_831	temp_832	temp_833	temp_834	temp_835	temp_836	temp_837	temp_838	temp_839	temp_840	temp_841	temp_842	temp_843	temp_844	temp_845	temp_846	temp_847	temp_848	temp_849	temp_850	temp_851	temp_852	temp_853	temp_854	temp_855	temp_856	temp_857	temp_858	temp_859	temp_860	temp_861	temp_862	temp_863	temp_864	temp_865	temp_866	temp_867	temp_868	temp_869	temp_870	temp_871	temp_872	temp_873	temp_874	temp_875	temp_876	temp_877	temp_878	temp_879	temp_880	temp_881	temp_882	temp_883	temp_884	temp_885	temp_886	temp_887	temp_888	temp_889	temp_890	temp_891	temp_892	temp_893	temp_894	temp_895	temp_896	temp_897	temp_898	temp_899	temp_900	temp_901	temp_902	temp_903	temp_904	temp_905	temp_906	temp_907	temp_908	temp_909	temp_910	temp_911	temp_912	temp_913	temp_914	temp_915	temp_916	temp_917	temp_918	temp_919	temp_920	temp_921	temp_922	temp_923	temp_924	temp_925	temp_926	temp_927	temp_928	temp_929	temp_930	temp_931	temp_932	temp_933	temp_934	temp_935	temp_936	temp_937	temp_938	temp_939	temp_940	temp_941	temp_942	temp_943	temp_944	temp_945	temp_946	temp_947	temp_948	temp_949	temp_950	temp_951	temp_952	temp_953	temp_954	temp_955	temp_956	temp_957	temp_958	temp_959	temp_960	temp_961	temp_962	temp_963	temp_964	temp_965	temp_966	temp_967	temp_968	temp_969	temp_970	temp_971	temp_972	temp_973	temp_974	temp_975	temp_976	temp_977	temp_978	temp_979	temp_980	temp_981	temp_982	temp_983	temp_984	temp_985	temp_986	temp_987	temp_988	temp_989	temp_990	temp_991	temp_992	temp_993	temp_994	temp_995	temp_996	temp_997	temp_998	temp_999	temp_1000
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Generating Graphs for Temp, Current and Speed for individual cycles, saving directly into directory folder ... It will take several mins

When file save completes some summary graphs of all cycles will be shown and cycle's individual graph



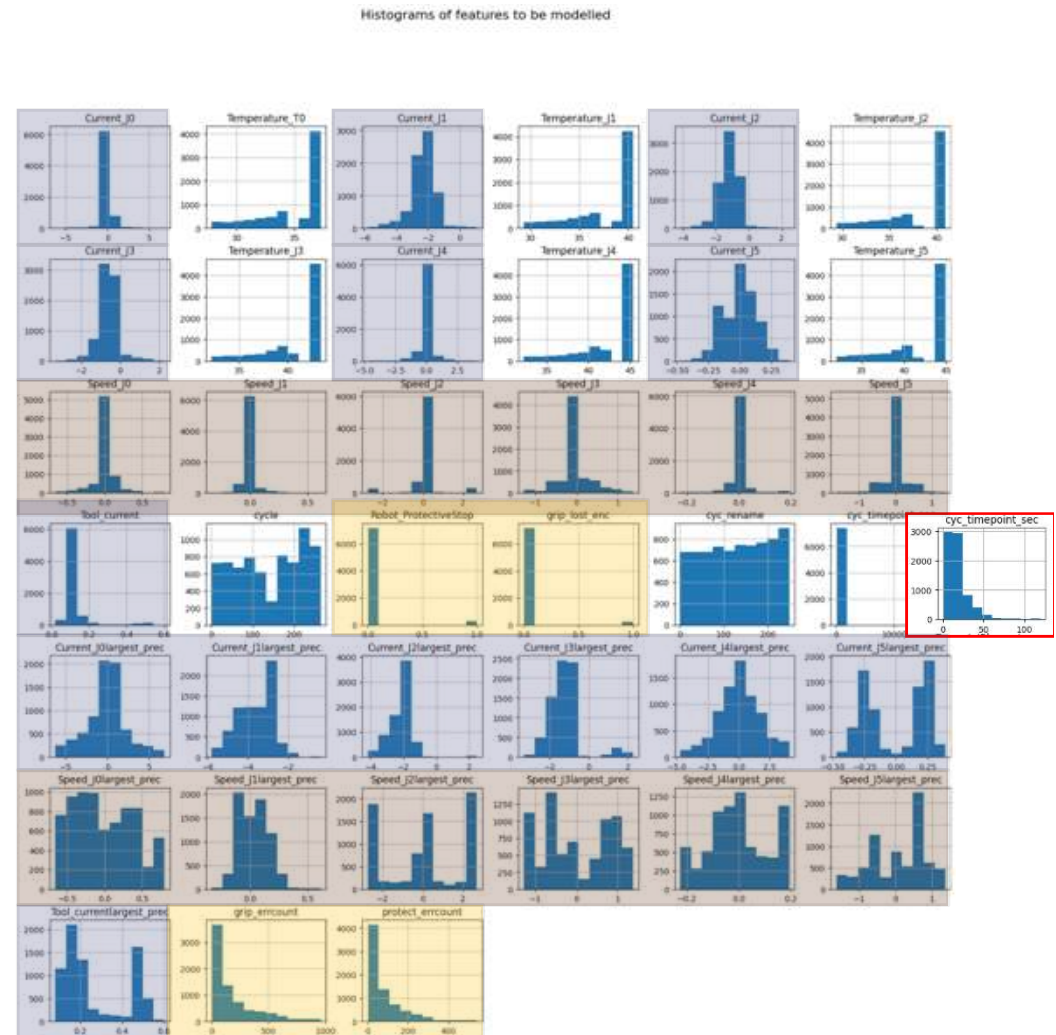
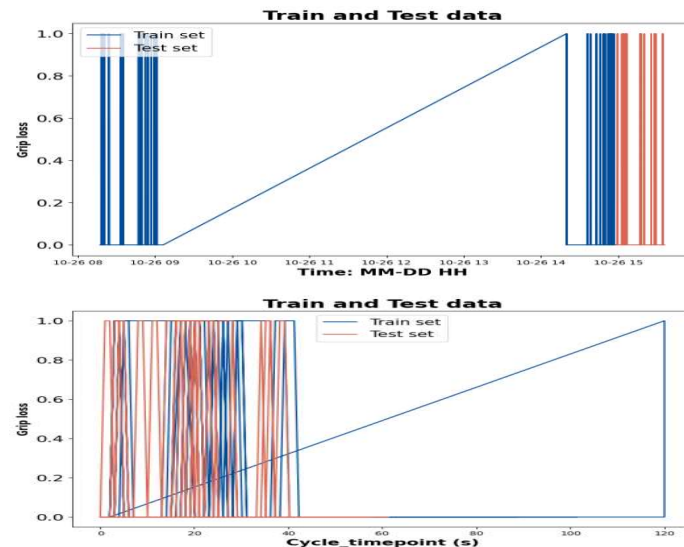
247	248	263	0	0	2022-10-26 15:35:21	2022-10-26 15:34:57	25	37.125	40.25	40.6875	43.3125	45.25	44.5	0	24.135	1.00
248	249	264	0	4	2022-10-26 15:36:06	2022-10-26 15:35:22	45	37.1875	40.3125	40.6875	43.375	45.25	44.5625	4	44.264	

These are the cycles where grip loss(es) occurred:

value
193
196
198
218
219
220
223
232
235
236

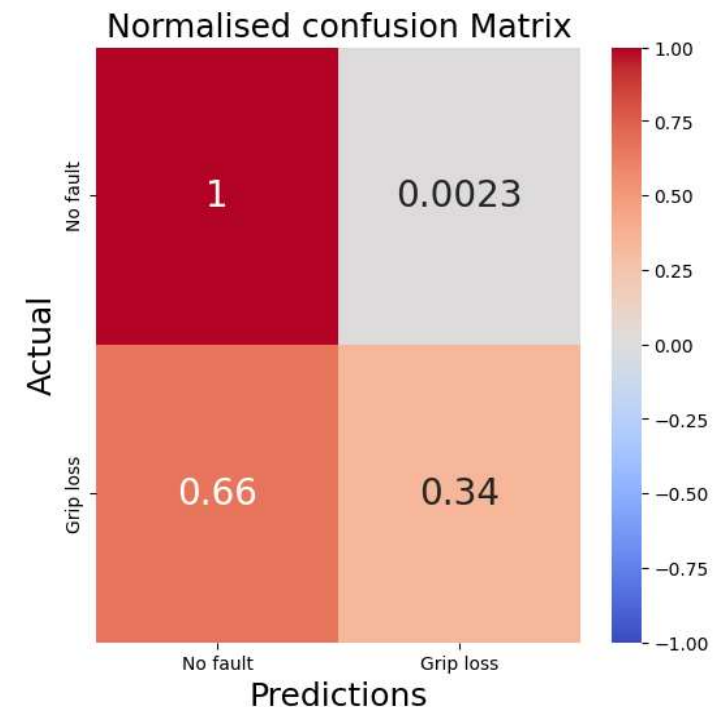
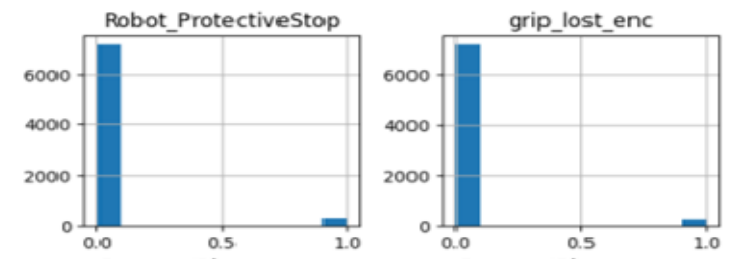
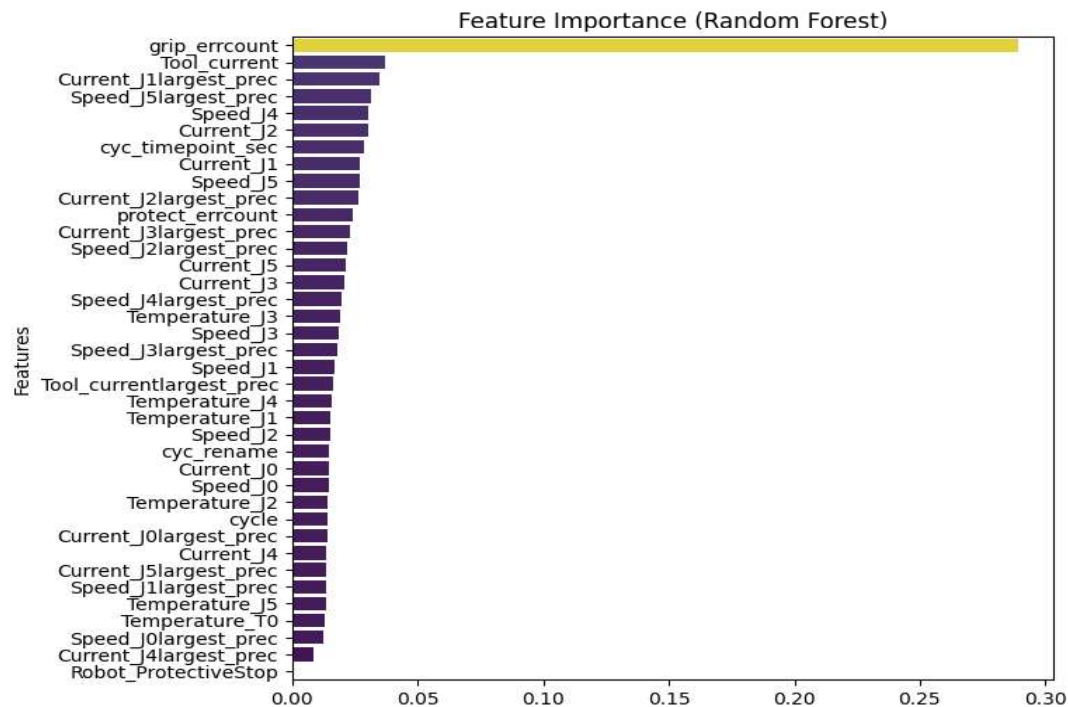
Machine Learning (ML) modelling prep

- Timeseries - Ideally predict next fault/error based on previous data of day. (80/20 trainin/testing dataset)
 - Used AutoML AutoGluon to check feasibility but returned no models – likely due to large chunks missing data
- Transform the dataset so can solve with traditional, tabular classification algorithms - Connect data from previous rows
 - **Errors/faults** – Very imbalanced, mostly no errors/faults
 - **Errors/faults** – Count up how long since last error happened
 - **Current** and **speed** – look back at previous 10 rows and extract the number of largest magnitude (positive or negative)
 - Removed timestamp - covered by cycle and cycle timepoint
 - **Clipped cycle timepoint (secs)** to remove several hour outlier
 - AutoML AutoGluon suggested RandomForest and KNN, among others
- Ref: https://stackoverflow.com/questions/44744584/multiple-time-series-with-binary-grip_lost_enc-prediction



ML modelling - results

- Data scaled
- Random Forest and KNN trialled based on AutoGluon results
- Due to imbalanced data, high accuracy but not good at predicting the grip loss correctly
- Best Random Forest gave AUC of 0.67 (measures how well predicts both outcomes), accuracy 0.97 or 97%
- Unsurprising that the count of how long since last error happened has high importance



ML modelling considerations

- Want to predict rest of days risk of errors/faults but need some information about what robot plans to do
 - Inconsistent cycle time which errors add to
 - hard to provide in advance for modelling
 - Discuss with team if can correlate robot programmed actions to this data better
 - Potentially better predictability if can generate expected robot actions and relate it back to the data the UR3 cobot is generating
- Dataset authors using Information Flow Based – Fuzzy Cognitive Maps (IF- FCMs) to help predict machine operations – may be better approach to investigate
 - modification of FCMs – visual modelling approach. Image on right shows FCM of government control of tobacco. Part of modelling is to adjust weightings of interactions

References IF-FCMs and FCMs

- Tyrovolas, M., Stylios, C., Aliev, K., Antonelli, D. (2024). Leveraging Information Flow-Based Fuzzy Cognitive Maps for Interpretable Fault Diagnosis in Industrial Robotics. In: Camarinha-Matos, L.M., Ferrada, F. (eds) Technological Innovation for Human-Centric Systems. DoCEIS 2024. IFIP Advances in Information and Communication Technology, vol 716. Springer, Cham. https://doi.org/10.1007/978-3-031-63851-0_6
- Tyrovolas, M., Liang, X.S. & Stylios, C. Information flow-based fuzzy cognitive maps with enhanced interpretability. *Granul. Comput.* 8, 2021–2038 (2023). <https://doi.org/10.1007/s41066-023-00417-7> (Link to github [marios-tyrovolas/Information-Flow-Based-Fuzzy-Cognitive-Maps-with-Enhanced-Interpretability](https://github.com/marios-tyrovolas/Information-Flow-Based-Fuzzy-Cognitive-Maps-with-Enhanced-Interpretability): Information Flow-Based Fuzzy Cognitive Maps with Enhanced Interpretability)
- Mkhitaryan et al. BMC Public Health. (2023) How to use machine learning and fuzzy cognitive maps to test hypothetical scenarios in health behavior change interventions: a case study on fruit intake <https://doi.org/10.1186/s12889-023-17367-z>

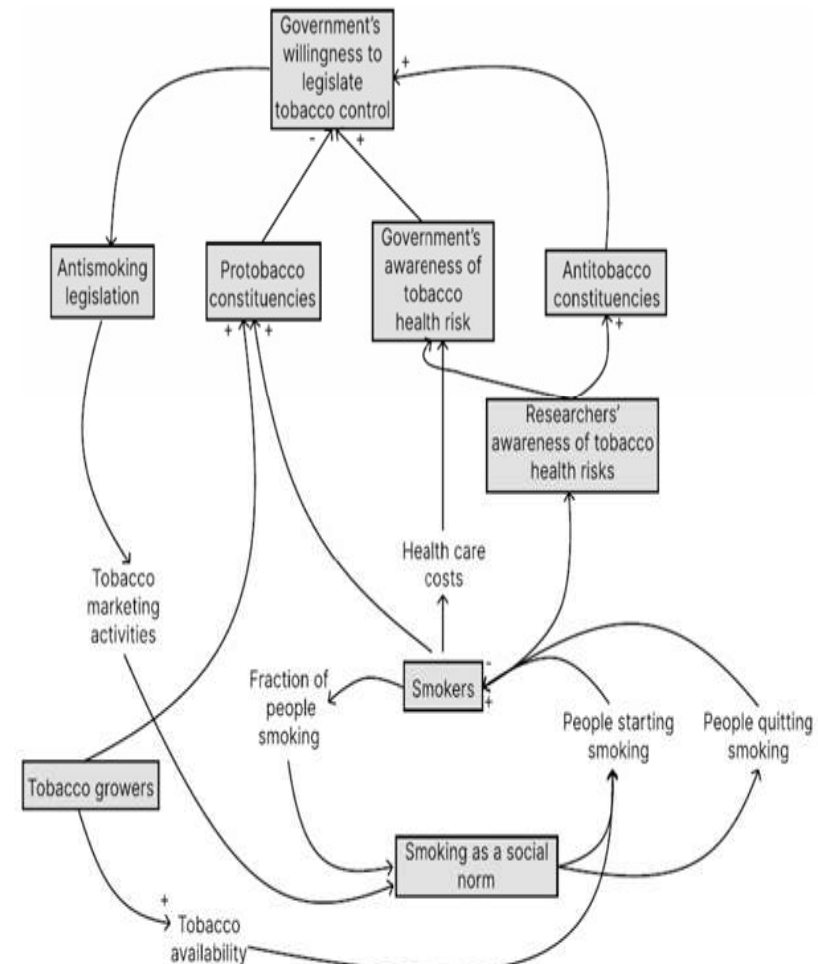


Fig. 2 An excerpt of a more complex logic model of government control of tobacco [7]

Conclusions and Recommendations

- Extensive exploratory data analysis lead to greater understanding of UR3 Cobot behaviour
 - This should help with process understanding, optimisation and planning
 - Generation of application to view summary data from UR3 Cobot logs to support this - to be deployed on Docker
- More knowledge from team about desired outcome of cycles, impacts of inconsistent cycle times and what other data it would be useful to explore/make available to them
- IF-CMs may be a better approach to automation/robotics operations modelling compared to traditional machine learning methods

Thank you! Q&A?